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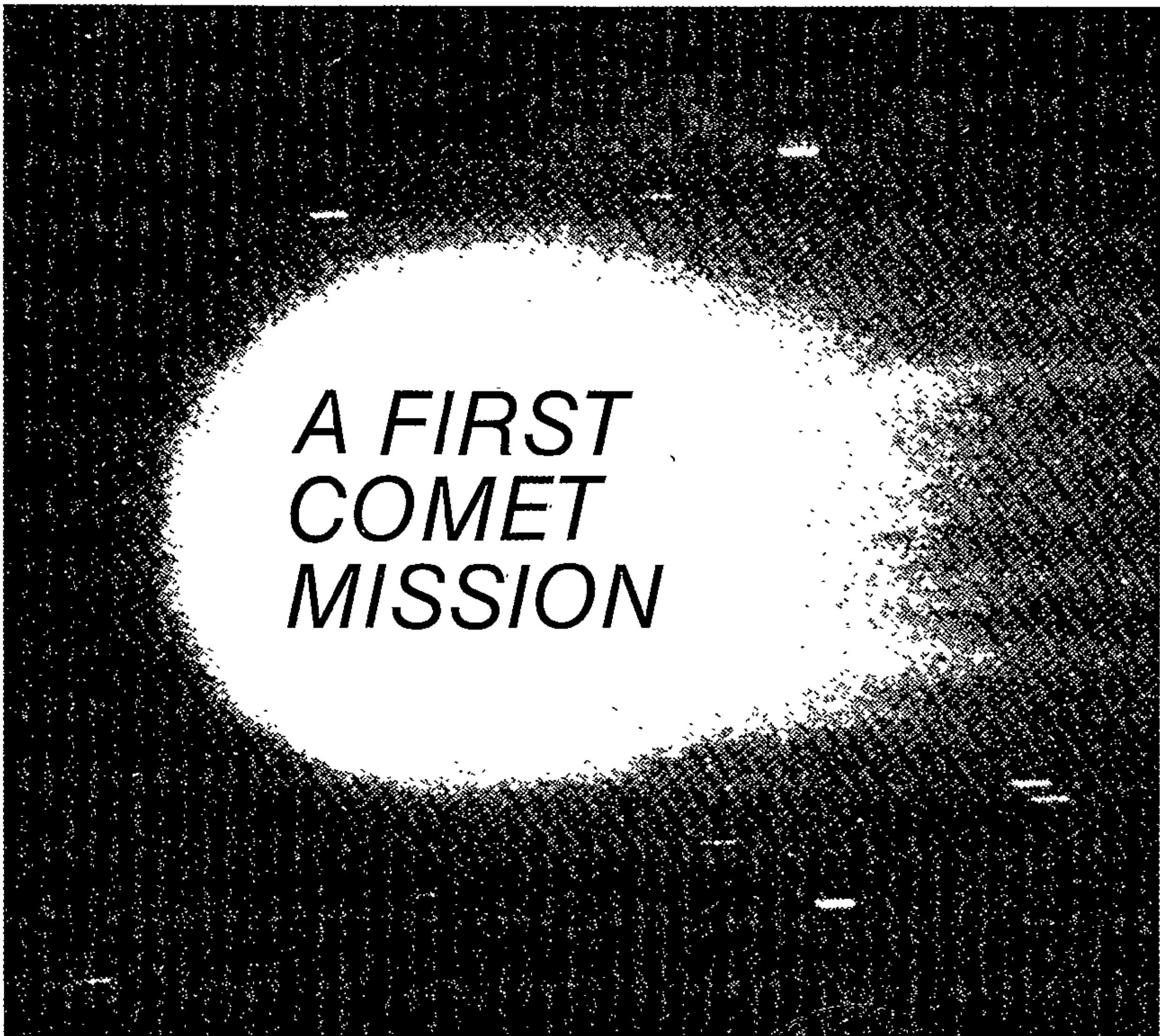

A FIRST COMET MISSION

Report of the Comet Halley Science Working Group

July 1977

NASA TM-78420

SCIENTIFIC RATIONALE AND STRATEGIES FOR A FIRST COMET MISSION

REPORT OF THE COMET HALLEY SCIENCE WORKING GROUP

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"...we are in great danger of being too smart."

- Joseph Veverka
April 6, 1977

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SECTION I
INTRODUCTION

A. BACKGROUND

The study of comets is essential to understanding the basic physical and chemical processes involved in the formation and evolution of the solar system. The proposal to use the enormously impressive solar sail or ion drive propulsion schemes to rendezvous with Comet Halley evokes a partly emotional, partly intuitive, but extremely positive response from most scientists. In January, 1977, the National Aeronautics and Space Administration formed the Comet Halley Science Working Group (CHSWG) to determine whether that response was founded on solid, logical grounds; whether, in fact, Comet Halley is the best target for a first comet mission; and whether a rendezvous mission has enough scientific leverage to justify a major increment in expense over a flyby mission. Our study has been conditioned not only by the findings of five previous study groups, most of which included a Halley mission in their recommendations, but also by the recommendation made by the Committee on Planetary and Lunar Exploration to the Space Science Board in 1975:

> "COMPLEX considers the study of comets to be of major importance and recommends that efforts be directed toward establishing the nature and quality of scientific experiments that could yield important data in a comet encounter so that the role of a comet mission can be properly assessed in the framework of the current strategy."

We, therefore, have seriously considered the ability of candidate instruments to make valid measurements. Finally, the capability of the solar sail and ion drive systems to land on a comet and, in future missions, to return a cometary sample to Earth, has led us to place some emphasis on the nature and scientific potential of a landed cometary observatory.

B. SCIENCE WORKING GROUP ORGANIZATION AND FUNCTIONS

The Comet Halley Science Working Group consists of the following nineteen scientists whose interests span the fields of cosmochemistry, planetary science, cometary physics, space physics, and aeronomy.

Members of CHSWG

Michael J. S. Belton (Chairman)	Kitt Peak National Observatory
John C. Brandt	Goddard Space Flight Center
Leonard F. Burlaga	Goddard Space Flight Center
Armand Delsemme	University of Toledo
Hugo Fechtig	Max Planck Institute for Nuclear Physics, Heidelberg
Martha Hanner	Max Planck Institute for Astronomy, Heidelberg
Andrew F. Nagy	University of Michigan
Marcia M. Neugebauer (Vice Chairman and Acting Project Scientist)	Jet Propulsion Laboratory
Ray L. Newburn (Executive Secretary)	Jet Propulsion Laboratory
Hasso B. O. Niemann	Goddard Space Flight Center
Tobias C. Owen	State University of New York, Stony Broo
Frederick L. Scarf	TRW Systems Group
Zdenek Sekanina	Center for Astrophysics
Gary E. Thomas	University of Colorado
Joseph Veverka	Cornell University
John T. Wasson	University of California, Los Angeles
George W. Wetherill	Carnegie Institution of Washington
Laurel L. Wilkening	University of Arizona
John A. Wood	Center for Astrophysics

Bertram D. Donn and David Morrison of NASA Headquarters were ex officio members of the group. Eugene Levy, of the University of Arizona, attended our meetings as a representative of the Committee on Planetary and

Lunar Exploration (COMPLEX) of the Space Science Board. We also benefitted from the attendance of our guest Dr. Fred Whipple at two meetings.

The functions of the group were defined as follows:

(1) Review the science objectives of a first comet mission, relating these to what is now known or can be expected to be learned in the near future from ground-based and near-Earth observations.

(2) Define a typical set of instruments and the science objectives of each for a mission to Comet Halley during its 1985/86 apparition.

(3) Consider the relative science values of a fast flyby (>10 km s^{-1}), a slow flyby (<10 km s^{-1}), or a rendezvous (negligible relative velocity), and discuss the impact of each on the typical instrument payload.

(4) Consider the relative scientific value of encounters with the comet at distances from the Sun ranging from 1 AU to 2.5 AU, including possible trade-offs between flyby velocity and distance.

(5) Consider the relative scientific value of pre- and post-perihelion encounters.

(6) Interact with the spacecraft design and mission design teams at the Jet Propulsion Laboratory to optimize these designs for scientific purposes.

In addition, the CHSWG was asked to provide a written report of its findings to NASA by July, 1977. To fulfill the above functions, CHSWG held the following four meetings during which the contents of this report were developed:

Date	Location	Topic
January 25/26, 1977	JPL	Organization and Orientation
March 9/10/11, 1977	JPL	Comet Science Workshop and Instrument Workshop
April 5/6, 1977	GSFC	Mission Strategy
May 3/4, 1977	GSFC	Backup and Alternate Missions/ Development of Concensus

Also, two subcommittees were formed to provide a more detailed assessment of a Cometary Lander Mission (J. Wood, Chairman) and a Tail Probe Spacecraft (F. Scarf, Chairman). The first of these held a special meeting on May 2, 1977, and both subcommittees reported to the full group on May 3.

SECTION II

SUMMARY: MAJOR CONCLUSIONS AND RECOMMENDATIONS

A. MAJOR CONCLUSIONS

The CHSWG offers the following statements of its major conclusions regarding strategies for a first comet mission.

1. General

(a) Halley is the only bright comet which displays the full range of cometary phenomena and has a sufficiently predictable orbit. It is by far the best choice for a first comet mission using low thrust propulsion systems. Its next two perihelion passages are in 1986 and 2061; thus, unless the first comet mission is to Halley, generations will pass before this very important object can be studied.

(b) Both the solar sail and the ion drive propulsion systems allow mission opportunities to Halley's Comet which accomplish most of the primary scientific objectives that we consider appropriate for a first comet mission.

(c) Because of the enormous scale ($\sim 10^5$ km for most gases) of a comet's atmosphere and the minuscule gravitational attraction (escape velocity ~ 2 m s^{-1}) of its nucleus, the character of the first mission to a comet must be substantially different from early missions to the planets. Consideration of the first cometary spacecraft as an atmospheric probe capable of descent onto the nucleus is technically viable, given the propulsion capability to achieve rendezvous.

2. Concerning Science

(d) A mission to a comet, particularly if it is of the rendezvous or lander type, offers a rich selection of measurement opportunities which, if exercised, could lead to major advances in our

understanding of basic physical and chemical processes in cosmogony, molecular astronomy, and space physics.

(e) The likelihood that the nuclei of new comets are nearly pristine samples of condensates from the protosolar system (possibly mixed with surviving pre-solar system interstellar dust) implies that measurements of their composition and physical constitution will yield fundamental information of the chemical and physical conditions that existed near the time of planetary formation as well as the processes of condensation, agglomeration, and mixing which were taking place.

(f) Characterization of the physical and chemical nature and of the processes of disintegration of a cometary nucleus is fundamental to an understanding of the relationship of comets to meteoroids, interplanetary dust, Apollo objects, volatiles and organic material accreted by the terrestrial planets, and the bodies responsible for cratering of the moon and planets. In addition most of our detailed knowledge concerning the state of the formative solar system has been obtained by chemical, petrological, and isotopic studies of meteorites. The principal uncertainty in the interpretation of these studies arises from our lack of understanding of their sources in the solar system. Evidence strengthening the relationship between active comets, possible extinct comets, and meteorites of any class will permit application of meteoritic data to comets with concomitant major advances in our understanding of comets.

(g) Of the comets with predictable orbits, Comet Halley has the largest gas production rate, and is, therefore, the best candidate for chemical analysis of minor constituents by mass spectroscopy. Given a rendezvous, with long integration times available, Comets Encke or Giacobini-Zinner are reasonable second choices.

(h) In the past, Comet Halley has exhibited the full range of cometary phenomena: dust tail, ion tail, outbursts, jets, shells, rays, non-gravitational forces and brightness variations characteristic of the vaporization of ices, and so on. Halley can therefore be

expected to be physically representative of the class of relatively fresh, active comets, some of which have been investigated in detail from Earth.

(i) The validity of existing physical and chemical models of the environment near an active comet nucleus is to be viewed with great caution. Large uncertainties exist, particularly in our understanding of the comet's ionosphere, associated electrodynamic phenomena, and the nucleus itself. Some of these uncertainties could perhaps be reduced by further theoretical and laboratory research and further observations of comets prior to the implementation of detailed strategy for a comet mission.

3. Concerning Mission Strategy

(j) The design of a rendezvous mission strategy should be based on the following considerations:

(1) We wish to sample as broad a range of cometary phenomena as possible. Cometary activity is variable in time, largely unpredictable, and poorly understood, but is generally greatest close to the Sun.

(2) The hazard due to dust is also variable, unpredictable, poorly understood, and greatest close to the Sun.

(3) We wish to investigate phenomena over a great range of scale sizes — from nuclear inhomogeneities of a meter or less to phenomena which may extend 10^8 km from the nucleus. Furthermore, we wish to study the dependence of remote phenomena on activity near the nucleus; i.e., we'd really like to be in several places at the same time.

(4) Realistic limits to the sensitivity and resolution of available scientific instruments must be recognized.

We conclude that:

(1) The conflict between scientific interests and the dust hazard requires a highly adaptive strategy with a capability for rapid response to data returned from the comet.

(2) Encounter should occur while the comet is less than 1.5 AU from the Sun.

(3) A preperihelion encounter is preferred.

(4) The nucleus should be approached slowly, making sequential measurements of physical processes of ever decreasing scale height.

(5) A specially instrumented tail probe would strongly enhance the scientific return from the mission.

(k) A rendezvous mission should terminate with an experimental descent onto the nucleus. The primary objective of this maneuver is to provide knowledge of the mechanical properties of the surface and of the hazards associated with landing. This knowledge will be invaluable for future cometary lander and sample return missions, as well as providing physical data unobtainable in any other way. Other things being equal, the descent should occur while the comet is observable from ground-based observatories.

(l) Because of the large scales involved in some cometary phenomena, their rapid time dependence, and their three-dimensional structure, supporting observations from the ground, from earth orbit, or from other spacecraft would contribute to a better understanding of the physical phenomena taking place. For Halley, this will be particularly true in the period March - August 1986, when a rendezvous spacecraft would be approaching the nucleus and the comet is visible prior to sunrise. (See Fig. B-1.)

4. Concerning Instrumentation

(m) Much of the instrumentation on a comet mission will be affected by outflow of dust from the comet. In some cases we know of no proven methods to combat this hazard, but concepts exist and must be investigated.

(n) The possibility of cometary rendezvous missions, which are characterized by long residence times and low relative velocities, eliminates many instrumentation problems.

(o) Space-qualified instrumentation suitable for quantitative compositional measurement of dust during a cometary rendezvous requires a major development effort.

(p) Space-qualified neutral gas and thermal ion mass spectrometers exist with enough sensitivity to adequately detect the anticipated populations of parent molecules, atoms, and ions during a Halley rendezvous. Mass/velocity spectrometers for energetic ions with resolution of the order of $m/\Delta m = \sim 50$ are currently under development and should be available in time for a Halley rendezvous mission. All of these instruments are susceptible to dust contamination, and means to prevent problems require development.

(q) The mass spectra of cometary neutrals and ions are expected to be extremely complex and will require considerable laboratory support both during and after the mission in order to arrive at an unambiguous interpretation. Remote sensing from the spacecraft of the spectra of individual molecular and atomic species by means of reflection and absorption spectroscopy in the UV and IR may aid in the interpretation.

(r) Global imaging of the nucleus to resolution better than 1 m is desirable to determine its heterogeneity at scales associated with the agglomeration of material into planetesimals and also to provide the information required for a successful experimental descent onto the nucleus and for future cometary lander missions.

(s) An accurate radar altimeter is required to determine the mass of the comet and to provide adequate ranging information for the interpretation of remotely sensed measurements. Sensitive accelerometers (down to 10^{-9}g) are also required for the mass determination. We understand that no technology development is required in either of these areas.

(t) There will be significant degradation of some of the scientific observations when the ion drive vehicle is thrusting, which is most of the time during cruise and some of the time after rendezvous. Straightforward mission and trajectory designs will allow frequent and acceptably long periods of free fall with no propulsion

associated interference. Although initial studies indicate that electromagnetic disturbances generated by the interaction of the solar or cometary winds with the sail or the concentrator/solar array structures are probably unimportant, some further study is advisable.

(u) Important for future lander missions is the development of a device(s) that will yield simple chemical separations to enhance the usefulness of a neutral mass spectrometer.

B. RECOMMENDATIONS

In summary, the CHSWG makes the following recommendations to the Office of Space Sciences in NASA.

1. On Mission Strategy

We recommend that the first comet mission be a rendezvous mission. We strongly prefer a rendezvous before perihelion of the comet. If this cannot be achieved, the rendezvous should occur as near to the Sun as possible.

2. On the Target for the First Comet Mission

We recommend that Comet Halley be chosen for the first rendezvous mission, because it is the only periodic comet with the following properties:

(a) It has a well known and reliable orbit and perfect record of behavior extending back more than two millennia.

(b) Its brightness and activity compare favorably with bright comets that have been physically studied before, and it displays the full range of cometary phenomena.

3. On the Preparing for a Comet Mission

We recommend that NASA provide strong support for the further development of flight instruments for a comet mission, for theoretical modeling

of physical conditions in cometary atmospheres, for supporting laboratory experiments, and for ground-based observations of comets. Pre- (and post-) mission simulation of flight experiments is also recommended.

4. Mission Termination

We recommend that the primary phase of the first comet rendezvous mission end with an experimental attempt to land on the surface of the nucleus. The descent to the surface should be carried out after the primary scientific objectives of the mission have been attained, and preferably when the comet is available for viewing from earth. Although we do not recommend this landing experiment as a primary objective of the mission, we do recommend that the spacecraft be designed so that there is the possibility of continued operation on the surface. If the landing experiment is successful and the spacecraft continues to operate, we recommend an extended mission phase for continued surface operations.

5. Hazards

The particulate matter impacting the spacecraft during close approach to the comet is expected to be a significant hazard to the successful operation of the spacecraft and experiments. We recommend that the following work be done:

(a) A detailed assessment of the physical characteristics of dust flux expected in the vicinity of a comet to be used as a guide to instrument development.

(b) A detailed assessment of what levels of integrated dust flux will result in significant degradation of instruments and of the operation of spacecraft subsystems.

(c) Evaluation of the means and cost involved in protecting exposed surfaces (e.g., optical surfaces) and in overcoming the effects of the dust flux on instruments which need to directly sample the ambient atmosphere (e.g., neutral and ion spectrometers).

6. Preparation for Future Missions

We recommend that, in planning a first comet mission, high priority be attached to those observations that prepare for future landing and/or sample return missions. These include high-resolution imaging, measurement of drag due to gas and dust, and determination of the mechanical strength of the nucleus surface.

SECTION III
SCIENTIFIC RATIONALE AND OBJECTIVES

A. BACKGROUND INFORMATION ON COMETS.

To understand the scientific objectives discussed below, it is first necessary to be aware of what is presumed known of the nature of comets.

At the center of cometary activity is the nucleus. This is the body of the comet, and it is thought to consist of a mixture of ices, mainly water, but also many other volatile molecules built of H, C, N, and O, and rocky material. The degree of compaction and the strength of the rocky material is not known, although some fraction exists as fine grains of dust and the overall structure may be very weak. The dimensions and mass of most cometary nuclei are inferred to be in the range 1 - 10 km and 10^{15} - 10^{18} g respectively. As a result, the gravitational attraction, or equivalently the escape velocity (1 - 5 m s^{-1}), is minute in comparison to that of planets.

Our knowledge of comets comes from the fact that the nucleus becomes active as it approaches the sun. Heated by solar radiation, the nucleus releases enormous amounts of gas and dust during its passage through perihelion. This unpredictable and often violent process produces an atmosphere of enormous extent. Neutral molecules, some highly reactive, are formed by sublimation and possibly other processes occurring very close ($<10^3$ km) to the nucleus and expand to distances of $10^5 - 10^7$ km. Some of these molecules participate in capricious bursts of activity in the form of jets and halos. Ionized molecules, also produced by very rapid, but poorly understood processes, have been observed in the inner parts of this atmosphere. In addition, ions are accelerated out of the central region to form a plasma tail. These tails, which show visual evidence of complex hydromagnetic phenomena (filaments, rays, kinks, and helices) have attained lengths approaching 2 AU in some comets and 1 AU in Halley. They are evidently tied to the flow of solar wind past the comet.

The streaming of gas out from the nucleus carries with it quantities of fine dust which is often responsible for much of the visual brightness of a comet. At distances $> \sim 10^4$ km from the nucleus, solar radiation pressure exceeds the aerodynamic drag force on the dust, which is then swept out of the comet's atmosphere to form a large, curved dust tail.

The great variety of scale sizes is illustrated by Fig. 3-1, which is a logarithmic drawing of typical cometary phenomena.

The orbital properties of comets show that they belong to the solar system. It is estimated that of the order of 10^{11} comets exist in a vast cloud around the Sun with a total mass which is perhaps greater than the mass of the Earth. For reasons we do not yet understand, this mass condensed into small bodies for which the internal pressure and temperature were not sufficient to cause differentiation or other physical changes. Thus, comets are probably the most pristine objects available for solar system studies. Furthermore, the outer skin of a comet is lost during each close passage by the Sun to expose fresh material for analysis.

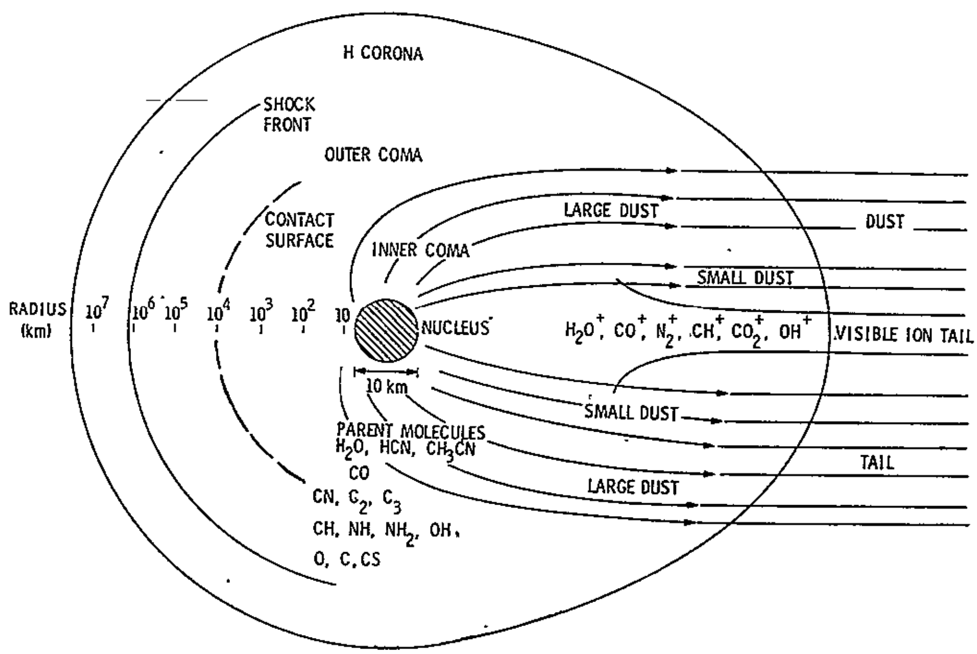

Figure 3-1. Sketch of Principal Features of a Comet on a Logarithmic Scale

Each year, only a hundred or so of these $\sim 10^{11}$ comets are newly deflected into the Jovian capture region (4 to 6 AU from the Sun) as a result of chance gravitational perturbations occurring in the distant reaches of the solar system. Occasionally the orbit of such a comet is then perturbed by the gravity of one of the major planets into a short period orbit. Many such comets exist and are characterized by only weak activity. Comet Halley is the brightest of the short period comets.

B. COMETARY MISSIONS AS AN ESSENTIAL INGREDIENT IN THE EXPLORATION OF SPACE

The study of comets is an essential component of any fundamental investigation of the solar system. This assertion can be supported at the most general level by recognizing the extraordinary combination of interest and awe that comets have evoked in the minds of humans throughout recorded history. The means to discover what they are and from whence they come are now available to us for the first time; it is only necessary to put these means to use. We already know enough about these mysterious denizens of the outer reaches of our solar system to realize their potential significance in the context of the larger problems of solar system origin and evolution which we are trying to understand. Their orbital and chemical peculiarities serve to illustrate their uniqueness.

Unlike the planets, which all move in roughly co-planar orbits, the long-period comets have a spherical distribution of orbits about the Sun. Their distribution in space is reminiscent of the distribution of globular clusters about the plane of their parent galaxy. The great mean distance of this halo or cloud of comets, some 50,000 AU from the Sun, further emphasizes their difference from the planets. The analogy with globular clusters is apt, since there are cosmogonic hypotheses in both cases that suggest these spherical symmetries represent a "memory" of the symmetry of the parent cloud of material that later collapsed and flattened to form the main system. This has suggested to some researchers that comets may be very old, possibly predating the ages of the planets themselves, so the material they contain may be representative of the earliest condensations in the interstellar cloud that ultimately formed the Sun and planets.

Chemically, the comets offer the apparent paradox of combining both oxidized and reduced constituents. In their spectra, we find evidence of CO_2 and CH, of NH_2 and N_2. If comets played an important part in delivering volatile material to the surfaces of the inner planets, as has been suggested, then a study of their composition should provide useful clues about the nature of the pre-biological chemical environment on the Earth. Since their chemistry may also be representative of condensations in the parent interstellar cloud, the study of comets may help us solve some pressing problems about molecule formation and the nature of the dust in the interstellar medium.

Another theory is that comets formed concurrently with the planets, in planar distribution in the vicinity of the outer planets, and were then gravitationally scattered to their present configuration. Comets may be samples of the "building blocks" or planetesimals from which the giant planets were constructed. If this is the case, we may expect that their study will yield new information on the degree of chemical disequilibrium, the physical state, the heterogeneity, and mixing processes at the time and place where they formed and will give insight into the processes of agglomeration and formation of planetesimals in the solar nebula.

Can these different hypotheses be tested? If we could obtain solid grains from comets and date them — either in situ or in returned samples — a chronology would be established that could determine whether or not the comets were spared the events that have reset the radioactive clocks in some classes of meteorites. However, radioactive dating experiments may not be feasible on a first comet mission. Determinations of isotopic ratios of the light elements, especially D/H and oxygen, could prove both practical and helpful; the D/H ratio depends strongly on the equilibration temperature of the nebula.

A knowledge of the composition of comets will also be critical in establishing their origin and their role in other aspects of cosmic chemistry. There is a general feeling that there is a continuity of relationships involving the large organic molecules found in dense interstellar clouds, the formation of planetary systems, the origin of comets and meteorites, and the delivery of C, N, H_2O and other volatiles to the surface of the primitive Earth. The discovery of

amino acids in some carbonaceous chondrites, the presence of the C_3 radical in comet spectra, the apparent existence of HCN and CH_3CN in both the interstellar medium and comets are all parts of this puzzle. Nevertheless, these relationships will remain vague until we have more precise information: what is the chemical state of a comet nucleus? What are the mysterious parent molecules whose fragments we see in comet spectra? Were they formed in the interstellar medium or are they local products of the solar system? What are the abundances of noble gases and other volatile elements? Are the dust grains in comets of the same type as the grains that produce the interstellar extinction and is there evidence that they have played a critical role in molecule formation? Are there agglomerations of non-volatile solids large enough to be considered meteoroids? It is possible to generate a virtually endless list of such questions, and while it will not be possible to answer all of them directly with experiments on the first comet mission, we should be able to obtain some deep insights. For example, we can expect a clarification of the nature of parent molecules and their relation to molecules found in interstellar space; a clarification of the processes by which cometary nuclei evolve and provide the awesome displays witnessed from Earth; and a clarification of their relationship to other matter in the solar system, such as meteorites, asteroids, and the interplanetary dust.

Are we all descended from comets which brought the vital elements for life to the surface of the Earth in ancient times? It is an arresting thought. The fact that we can ask such a question is a good indication of why we are so interested in these objects and how little we really know for certain about the early history of our own planet.

C. SCIENTIFIC OBJECTIVES FOR COMET MISSIONS

In the broadest possible terms we find that comet missions should address the following objectives:

(1) Determine the chemical nature and physical structure of the nucleus.
(2) Characterize the physical evolution of the nucleus during its passage by the Sun.

(3) Characterize the evolving chemical and physical nature of the atmosphere, ionosphere, and dust envelope.

(4) Characterize the interaction of a comet with the interplanetary plasma and determine the origin and physical nature of comet tails.

Table 3-1 indicates a host of specific scientific questions posed by these objectives.

For its full attainment, objective (1) requires both remote sensing and direct sampling of the nucleus. Direct sampling, which implies landing on the nucleus, is unrealistically ambitious for the first comet mission even though the technical capability to land from a rendezvous probably exists. The problem is that the absence of basic knowledge about the nucleus and its surface properties makes it impossible to plan rationally for such a mission at this time. Nevertheless we are of the opinion that a major part of objective (1) is achievable with present generation instruments at a close rendezvous and that the way can be paved for future landing and sample return missions. Table 3-2 lists some specific measurements related to objective (1) and what can probably be achieved by different mission modes. Table 3-2 serves to emphasize our conclusion that a rendezvous mission provides a powerful base for the achievement of many important aspects of objective (1). Of the seven objectives listed that would be better accomplished with a landing, only one (surface strength) seems absolutely to require a landing. Two others (internal homogeneity and age) may not be achievable without instruments operating on the surface. For the rest, a partial measurement capability exists at rendezvous, although it must be pointed out that in the case of the automated analysis of collected dust an aggressive developmental program is necessary to provide reliable space qualified instrumentation and collection devices.

The attainment of objectives (2), (3) and (4) requires extended observations of the cometary nucleus, atmosphere, and ionosphere at a range of distances from the nucleus. The requirement for long integration times emphasizes the basic strength of rendezvous missions over flyby missions and underscores the importance of low, continuous thrust, high energy propulsion systems in

Table 3-1. Specific Scientific Questions or Measurement Objectives that Could be Addressed on a First Comet Mission

SCIENTIFIC OBJECTIVE	SPECIFIC SCIENTIFIC QUESTION OR MEASUREMENT OBJECTIVE.
(1) Determine chemical nature and physical structure of the nucleus.	What are the mass and density of the cometary nucleus? What are the size, shape, and state of rotation of the nucleus? How homogeneous is the physical and chemical structure of the nucleus? In what way did the processes of condensation and agglomeration occur? What was the chemical state of the solar nebula? Where were the comets formed? What is the evidence for large scale mixing processes in the solar nebula? What can comets tell us about the interstellar gas and dust? Can we establish a firm physical link between cometary and meteoroidal material? What can we say about the implantation of volatiles by comets on the planets?
(2) Characterize the physical evolution of the nucleus during its passage by the Sun.	What can we learn about the evolution of comets? What causes "activity" on the nucleus? Is activity a surface or sub-surface phenomenon? How much material is lost by the comet during perihelion passage? How is it ejected from the nucleus? Does it come from specific places? Can we establish a link between cometary nuclei and the asteroids? What is the relationship between cometary and interplanetary dust?
(3) Characterize the evolving chemical and physical nature of the atmosphere, ionosphere, and dust envelope.	What is the nature and abundance of the different molecules and ions making up the cometary atmosphere? What is the velocity distribution of neutral and ionic species?

Table 3-1. Specific Scientific Questions or Measurement Objectives that Could be Addressed on a First Comet Mission (cont'd)

SCIENTIFIC OBJECTIVE	SPECIFIC SCIENTIFIC QUESTION OR MEASUREMENT OBJECTIVE
(3) (Continued) Characterize the evolving chemical and physical nature of the atmosphere, ionosphere, and dust envelope	Is there a collision zone in which gas phase chemical reactions take place near the nucleus? What are the "parent" molecules? What is the dominant ionization mechanism? Is it a steady or a transient phenomenon? What happens to the "parent" molecules in the atmosphere? What is the production rate of cometary gases and how does it vary? What are the "jets," "rays," "halos," "envelopes" seen from the ground? What is the gas to dust mass ratio? Do "icy" grains exist? What is their lifetime? What is the energy distribution of electrons and ions near the nucleus? What is the size distribution and flux of dust in the comet's atmosphere?
(4) Characterize the interaction of a comet with the interplanetary plasma and determine the origin and physical nature of comet tails.	What is the physical nature of tail phenomena observed from the ground? What insight can we gain from cometary phenomena about energetic geomagnetic and astrophysical phenomena? Is there a bow shock? Where is it? What is its physical character? Is there a contact surface? Where is it? What is its physical character? How are ions accelerated into the tail? Are strong magnetic fields developed near the comet? What role do wave motions and dissipation play in production of ionization and tail phenomena? Are large electric currents induced in the cometary atmosphere? What are the "filaments" and "motions" seen in the plasma tail?

Table 3-2. Measurements of the Nucleus

OBJECTIVE	OPTIMUM MISSION MODE	RENDEZVOUS CAPABILITY	FLYBY CAPABILITY
(1) Composition			
(a) Chemical composition of volatiles	Rendezvous	Mass spectroscopy (all volatiles); UV spectroscopy (many atoms, molecules, and ions); IR spectroscopy (certain ices)	Mass spectroscopy (major volatiles at distance ≥ closest approach; molecules break up on impact) UV spectroscopy
(b) Chemical composition of non-volatiles	Landing	X-ray fluorescence (Al, Si, Mg, Ca, Ti, Fe); IR spectroscopy (ices, sulfur, silicates); Collected dust α scatt. and/or X-ray (major elements) Dust particle counter and analyzer (improvement needed)	Impact dust analyzer
(c) Mineralogical composition	Landing and sample return	Collected dust X-ray diffr. (marginal) SEM-EDX (inst. needed)	
(d) Isotopic composition	Landing and sample return	Mass spectroscopy, UV spectroscopy } (D/H, C^{12}/C^{13})	
(2) Gross Physical Properties			
(a) Size	Rendezvous	Imaging and radar altimeter	Imaging
(b) Shape	Rendezvous	Imaging	Imaging
(c) Mass	Rendezvous	Radio tracking; radar, and accelerometer	
(d) Rotation	Rendezvous	Imaging	Imaging (only if rotation is fast)
(e) Age	Landing and sample return	Collected dust K-Ar dating (?)	
(3) Internal and Surface Properties			
(a) Surface Morphology	Rendezvous	Imaging (1m resolution) IR spectroscopy (5m resolution)	Imaging (several tens of m resolution; limited number of images, limited coverage)
(b) Temperature	Landing	IR radiometer (50m resolution)	
(c) Heterogeneity (lumpy, layered, core?)	Landing (seismometry)	Radar sounding (?)	
(d) Strength (hard, soft?)	Landing		

justifying a comet mission. Without advanced propulsion there is no rendezvous; and without a rendezvous there is little chance of adequately satisfying objectives (1), (2) and (3).

To satisfy (2) we rely primarily on a high quality imaging system which can monitor the activity of the nucleus as the comet passes through the inner solar system; to satisfy (3), the primary instruments are neutral and ion mass spectrometers, both of which are in a high state of development for space use. Only in characterizing the dust content of the comet's atmosphere do we find serious instrumental deficiencies.

These objectives also provide a basis for assessing the relative capability of missions characterized by postperihelion rendezvous (solar sail) and preperihelion rendezvous (ion drive). Clearly the latter mission strategy should lead to a more complete attainment of objectives (2), (3) and (4).

Objective (4) requires special consideration, for although we are satisfied that a powerful instrumental capability exists for making the necessary measurements, the phenomena associated with the comet tail are often so rapid (hours) and exist over such an enormous range of scales that instruments on a single spacecraft at rendezvous are not adequate to properly characterize the processes taking place. An independent instrumented tail probe, released from the main spacecraft, can resolve this problem and lead to the satisfactory achievement of objective (4).

D. SCIENTIFIC MERIT OF DIFFERENT TYPES OF MISSIONS

We can identify four types of cometary missions: flybys, rendezvous, landers, and sample return.

1. Flyby Missions

Flyby missions are characterized by a high relative velocity (>1 km s^{-1}) between the comet and the spacecraft which allows only a brief period of useful observing time (generally $< 10^4$s). The exploration strategy must be determined

in advance; there is no capability to modify the trajectory or timing in response to data obtained on hazards or on interesting cometary phenomena. There is limited capability to trim the encounter trajectory to guarantee a close passage by the nucleus. The quick, distant passage severely limits both the number and resolution of images obtained. Some remote sensing techniques (e.g., x-ray fluorescence spectroscopy and infrared spectroscopy) are not sufficiently sensitive to be useful on a flyby mission. Mass spectroscopy is impaired when the relative velocity is great enough (above $\sim$5 km s^{-1}) to break up molecules on impact.

Particle and fields experiments directed at characterizing the large scale topology of the interaction with the solar wind are not impaired by the high encounter velocities. On a flyby mission, they can provide a "snap shot" of the conditions in the comet and of its interaction with the solar wind. Also substantial velocities are an advantage for currently available dust analysis experiments which rely on energetic impacts of individual particles with the instrument.

2. Rendezvous Missions

Rendezvous missions are characterized by very low velocities ($\sim$1 m s^{-1}) relative to the comet with the capability for maneuvering near the nucleus for extended periods of time (many months). The low gravity allows complex flight paths about the nucleus with only modest demands on spacecraft propulsion capability. It is therefore possible to sample important parts of the cometary atmosphere as desired. Mass spectroscopy can be performed using developed techniques and instrumentation. Long observing times and the ability to regulate the distance from the nucleus provide an enhanced capability for the detection of minor volatile constituents and to study the evolution of cometary gases as they flow outwards (parent molecules, chemical reactions, dissociation, ionization, and acceleration). Opportunities for remote sensing of the nucleus are excellent. Imaging and spectroscopy of the nucleus are possible with adequate resolution, coverage, and signal-to-noise ratio to characterize its rotation, global structure and heterogeneity, dynamics, and

physical evolution during perihelion passage. An accurate determination of the mass and mean density of the nucleus is also possible. The possibility of extended periods near the nucleus also makes probable the capability of remotely analyzing the surface of the nucleus with x-ray, and possibly γ-ray, spectroscopy. Rendezvous unfortunately renders useless existing dust analyzers which rely on high impact velocities. More sensitive dust detectors are currently under development. However, there seem to be no difficulties of principle as to why outflowing cometary dust cannot be collected in sufficient abundance for analysis by more traditional methods.

3. Landed Missions

Any landing on the nucleus would be preceded by weeks of cometary studies similar to those performed by a rendezvous mission. The ability to land and operate on the surface of the nucleus would allow the direct examination of its structure. Close up imaging would reveal the degree of aggregation and the physical relationship of solids and ice. Elaborate chemical analysis of solids and ices becomes possible by several different techniques to provide the best chance to analyze the mysterious parent molecules and to establish whether a physical link between comets and meteorites exists.

4. Sample Return

Sample return allows many types of material analysis that are simply too complex to be handled remotely: these include most radiometric dating and other isotopic studies, detailed mineralogical analysis of silicates, some studies of organics, and mineralogic evidence of the thermal history of the silicate components. Any link with meteorites can be unambiguously confirmed.

There is also a possibility that some fraction of the cometary dust is preserved interstellar dust. Individual grains may exhibit substantial variety, and each may have a wondrous story to tell; but it is recorded on a microscopic scale and is unlikely to be read anywhere except in terrestrial laboratories.

E. HALLEY'S COMET AS A CANDIDATE FOR THE FIRST COMET MISSION

The selection of a candidate for the first cometary mission may be reduced to three criteria; we want:

(1) A comet with a reliable orbit which is well known years in advance.

(2) A moderately bright comet whose behavior can be predicted with confidence and which is known to exhibit a broad range of cometary phenomena.

(3) A "young" comet whose properties have been only slightly changed by the environment of the inner solar system.

The first and third criteria are contradictory, and the first criterion is necessary for mission planning; it restricts the choice to short period comets. Table 3-3 lists the brighter short period comets which pass through perihelion before the end of 1990.

Criterion (2) eliminates from serious consideration all except three of the comets in Table 3-3: Halley, Encke and Giacobini-Zinner. Of the brighter comets on the list, Ashbrook-Jackson fails because of its large perihelion distance (no strong ionization or tail phenomena expected) and Brorsen-Metcalf and Schaumasse because of their unpredictable behavior. Comet d'Arrest is a poor producer of tail phenomena, and, in 1989, it will be less than 1° from the Sun at perihelion, making observations from Earth extremely difficult.

Given the capability to perform a rendezvous mission with a high inclination comet, Comet Halley clearly stands out as the best candidate. Halley is probably much "younger" than either Encke or Giacobini-Zinner. It also displays great activity and the full range of cometary phenomena of which we are aware. Its brightness implies gas production rates at perihelion which are a hundred times greater than its nearest competitor, Comet Encke, thereby ensuring the best chance of measuring minor constituents by mass spectroscopy. In addition, the brightness of Halley has been documented over some 20 past perihelion passages and shows secular decrease of $\lesssim 0.2$ magnitudes

Table 3-3. Candidate Comets

COMET	PERIOD, yr.	INCLINATION, deg.	PERIHELION DISTANCE, AU	PERIHELION DATE	ABSOLUTE MAGNITUDE, H_{10}	ESTIMATED PRODUCTION RATE AT PERIHELION (HALLEY = 100)
Schaumasse	8.2	11.8	1.21	1/7/84	7.8	1.3
Encke	3.3	11.9	0.34	3/27/84	11.4	0.6
Giacobini-Zinner	6.5	31.9	1.03	9/6/85	10.0	$\lesssim$0.3
Ashbrook-Jackson	7.4	12.5	2.31	1/24/86	6.7	1.0
Halley	76	162.2	0.59	2/9/86	4.6	100
Grigg-Skjellerup	5.1	21.1	0.99	6/20/87	faint	Low
Encke	3.3	12.0	0.34	9/17/87	11.4	0.6
Borrelly	6.8	30.3	1.36	12/18/87	9.5	$\lesssim$0.2
Reinmuth 1	7.6	8.1	1.87	5/10/88	faint	Low
Tempel 2	5.3	12.4	1.38	9/16/88	11.5	Low
Brorsen-Metcalf	71.9	19.3	0.48	9/29/89(?)	9.6	1.6
d'Arrest	6.4	19.4	1.29	2/4/89	8.3-11.9	Low
Pons-Winnecke	6.3	22.3	1.26	8/19/89	~13	Low
Honda-Mrkos-Pajdusakova	5.3	4.2	0.54	9/13/90	faint	Low
Encke	3.3	12.0	0.34	11/3/90	11.4	0.6

per passage, ensuring that its brightness in 1986 can be predicted with some confidence.

A second point in favor of Halley is that all of the score of comets that have been studied in detail in modern times were (moderately) bright comets (i. e., of the Halley's brightness class). A Halley mission, therefore, has the advantage that its scientific results can more confidently be extended to a class of objects of which we have some detailed experience and physical understanding.

Although Halley is our first choice, it should be noted that comets Encke and Giacobini-Zinner are also viable scientific targets. Like Halley, they have been observed for many apparitions and have predictable orbits. However, most phenomena at these comets occur on a smaller scale. Minor constituents measurable at Halley might remain undetected at Encke or Giacobini-Zinner. On the other hand Encke may be relatively free of dust and, while this might be considered a scientific disadvantage, it could be a substantial engineering advantage in the first mission. It is not possible to estimate the hazard associated with the flux of very large particles which Encke may still emit.

F. PHYSICAL MODELS FOR COMETS

In planning for a cometary mission, a physical model is essential for predicting the environment to which the spacecraft will be exposed and to evaluate what the scientific return of the mission might be. More specifically, reliable physical models are required to arrive at the best scientific payload, to determine the range of sensitivity of instruments, to plan the mission strategy and timetable for various observations, to estimate what spacecraft propulsion capability is needed, and to evaluate what hazards might exist for the spacecraft and its payload.

Recent apparitions of several bright comets, (e.g., Arend-Roland, Bennett, Kohoutek, West), an increasing ability to make observations from space (OAO; Copernicus, Mariner 10, Skylab rockets) at ultraviolet, infrared, and radio

wavelengths, plus well organized cooperative observational efforts have led to an upswing of scientific activity and knowledge concerning comets. Highly recommended reviews and collections of original papers are: Report of Commission 15 (Physical Study of Comets, Minor Planets and Meteorites) to I.A.U. (A. H. Delsemme, 1976); "Comet Kohoutek" (ed. by G. A. Gary, 1975, NASA-SP-355); "The Physical Study of Comets" (Parts 1 and 2, ed. by B. Donn, et al., NASA-SP-393).

The CHSWG is of the opinion that while our ignorance of the nature of comets remains profound, it is now possible to make physical models of comets and their average behavior comprehensive enough to meet the needs stated above. A first attempt to construct a physical model of Halley, together with an indication of what can be done and what the uncertainties are, is included as Appendix A. An Encke model is already available ("Ballistic Intercept Missions to Comet Encke," M. Mumma, Editor, NASA TM X-72542, March, 1975). A similar model could be generated for Giacobini-Zinner, although we have not done so.

It is particularly important to point out that much more refined work can be done (particularly in modeling physical processes in the inner coma and ionosphere) and, as we indicate in our recommendations, shouldbe initiated now if the results are to impact the design of a Halley rendezvous mission.

SECTION IV

SPACECRAFT AND INSTRUMENTAL CAPABILITIES FOR A COMET MISSION

A. THE IMPORTANCE OF LOW THRUST PROPULSION SYSTEMS FOR COMET MISSIONS

The characteristic acceleration of the ion drive and solar sail propulsion systems being considered is $\sim 10^{-1}$ cm s^{-2} at 1 AU. Operation in space for a year at this very small acceleration leads to a momentum exchange equivalent to some 30 km s^{-1}, roughly the orbital velocity of the Earth. This example emphasizes the fact that, as far as the inner solar system is concerned, low thrust systems using radiant solar energy can, once liberated from the Earth's gravity, provide mission opportunities not available with conventional ballistic rocket systems.

Ballistic rockets can provide a flyby of virtually any comet with a predictable orbit; but, even in the best cases, the encounter velocities are ~ 5 km s^{-1} and more typically, 15-20 km s^{-1}, which provides limited opportunities for scientific investigation (see Section IIID). In the specific case of Comet Halley, which all previous working groups have highly recommended as an objective, the ballistic flyby velocities reach $\gtrsim 55$ km s^{-1}.

Ion drive and solar sail both provide opportunities to reduce flyby velocities to zero, that is to rendezvous with any of the comets previously considered, including Halley, while still maintaining a large payload capability. As we shall see, the scientific payoff should be truly enormous.

B. TYPICAL INSTRUMENT PAYLOADS

We have considered instrument payloads for various types of missions from the point of view of assessing how well measurements from certain types and classes of instruments meet the basic scientific objectives of a cometary mission. The typical payloads discussed below are examples made up of

instruments which we believe could be ready (in the case of rendezvous and flyby missions) for a 1981-82 launch. We have not yet attempted to identify recommended payloads or even "core" instrumentation. Realistic weight, power, and most importantly, cost constraints were not available to accomplish the former task; and we avoided the designation of "core" instruments (most of which should be obvious) for philosophical reasons.

1. Typical Payload and Measurement Objectives for a Rendezvous Mission

Table 4-1 lists the instruments that we consider should be included as part of a typical instrument payload. A visible-light photopolarimeter was not included as it was felt that most of the measurements for which it would be useful could either be done from the ground or could be done with one or another of the instruments included in the list.

Table 4-2 indicates the chief measurement objectives and anticipated capabilities of the typical instruments. Their relationship to the scientific objectives (see Section IIIC) and the expected scientific payoff is shown in Table 4-3. These two tables illustrate our conviction that it is possible to formulate a scientific instrument payload, out of developed or conceptually feasible instrumentation, that can achieve major contributions to all of the scientific objectives. The areas of major deficiency are to provide suitable hardware to combat the dust hazard, to measure accurately the flux and mass spectrum of escaping cometary dust particles, and to collect, organize and make elemental measurements on dust particles.

Most of the instrumental capability requirements on Table 4-2 are obvious (cf. Appendix A). The rationale for requiring global coverage of the nucleus at resolution better than 1 m needs special discussion. One consideration is that the chances of successful landing are greatly enhanced by resolution at least to the same scale as the spacecraft. There is also scientific justification for good spatial resolution.

Table 4-1. Typical Science Payload for a Rendezvous Mission

SCIENCE INSTRUMENTS	WEIGHT, kg	POWER, w	DATA RATE, bps	HERITAGE*	COMMENTS
1. Neutral Mass Spectrometer	10.0	15	1.6k	PVO	Scan Platform
2. Thermal ion mass spectrometer with retarding potential analyzer	5.0	6	500	DE	Scan Platform
3. Ion mass and velocity solar wind analyzer	9.0	5	400	NEW	Scan Platform
4. Magnetometer	3.0	4	300	M10, P10	Boom Mounted
5. Plasma Wave Detector	5.5	4	200	P6	2 antennas (3-4m)
6. Electron Analyzer	3.0	2	500	M10	Boom Mounted
7. Ultra Violet Spectrometer	3.0	4	100	PVO	Scan Platform
8. Near IR Spectrometer	8.0	8	200	M9	Scan Platform
9. Imaging: High Resolution	18.0	15	50k	MJS	Scan Platform. Heritage refers to telescope. CCD Sensor.
Wide Angle	15.0	15	50k	M9	
10. Radar Altimeter	7.0	10	100	NEW (LPO)	1 meter diam antenna
11. IR Radiometer	9.0	4	200	M9, Viking	Scan Platform
12. Orbital X-Ray Fluorescence	8.0	5	100	NEW (LPO)	Bus mounted, face nucleus + sunward sensor
13. Dust-Counter	2.5	5	100	HEOS	Boom Mounted
14. Collected Dust Analyzer (Electron Microscope or α p/X-Ray Scattering)	2.0-10.0	1-5	5k	NEW (Surveyor)	Low duty cycle
15. Landed Science	~5	<1	~1	Various	
TOTALS	113-121 kg	104-108w**	110.3 kbps**		
16. Tail Probe Instruments	21	23	20	P6	

*PVO: Pioneer Venus (Orbiter) M10: Mariner 10 P10: Pioneer 10 P6: Pioneer 6
M9: Mariner 9 MJS: Voyager LPO: Lunar Polar Orbiter DE: Dynamic Explorer

**Actual total lower because of time sharing.

Table 4-2. Primary Measurement Objectives and Capabilities of Typical Instruments for Rendezvous

INSTRUMENT	PRIMARY MEASUREMENT OBJECTIVES	DESIRED INSTRUMENT CAPABILITIES	FLIGHT INSTRUMENT DEVELOPMENT STATUS
Neutral Mass Spectrometer	Identification of "parent" molecules Atmospheric chemistry and neutral gas flow Isotopic composition of volatiles	Mass range: 1-250 AMU Mass resolution $\Delta m = 1$ AMU (1-250 AMU) poorer resolution acceptable at higher mass numbers Dynamic range: $\sim 10^8$ Sensitivity: $\gtrsim 10^3$ Mol. cm^{-3}	Good instruments exist Add dust protection
Thermal Ion Spectrometer	Ionic composition, temperature and velocity Identification of ionization mechanisms near comet	Mass range: 1-100 AMU (at least) Mass resolution $\Delta m = 1$ AMU Sensitivity: $n \geq 1$ ion cm^{-3} $T > 150°K$ $V > 40$ m s^{-1}	Good instruments exist Add dust protection
Ion Mass and Velocity/ Solar-Wind Analyzer	Acceleration of ions near comet to form tail Interaction of solar wind with comet (bow shock; contact surface: stability)	Mass range: 1-100 AMU Mass resolution $\Delta m = 1$ AMU Velocity range: 1-400 km s^{-1} Flux range: $10^4 - 10^9$ cm^{-2} s^{-1} ion^{-1}	Need better mass resolution than available Need dust protection
Magnetometer	Magnetic properties of ionosphere and relation to ionization and ion acceleration mechanisms Interaction of solar wind with comet Magnetic field of nucleus	Field range: $10^{-1} - 10^3 \gamma$ 3 axis type; rapid response	Good instruments exist
Plasma Wave Detector	Relation of plasma and field instabilities to ionization and ion acceleration mechanisms Interaction of solar wind with cometary atmosphere	Wave modes: electrostatic, hydromagnetic, electromagnetic Response: $\sim 10^{-1} - 10^5$ Hz Sensitivity: $>10^{-1}\gamma$ $>10^{-5}$ v m^{-1}	Good instruments exist
Electron Analyzer	Ionization phenomena near nucleus Interaction with comet of solar wind	Energy range: ~1 eV to several keV Sensitivity: $0.1 - 10^5$ electrons cm^{-3}	Good instruments exist Need dust protection
Ultraviolet Spectrometer	Atmospheric and ionic composition and production rates Scales of observable species Dust albedo and distribution about comet	Wavelength range: 1100 - 4000 A Resolution: ~10 Å	Good instruments exist Need dust protection
Near IR Spectrometer	Chemical homogeneity of nucleus Identify some ices and non-volatiles	Wavelength range: 0.8 - 5 μm Resolution: 50 - 100 A Field of view: 10^{-3} rad	Current technology adequate Reconfigure to optimize for comet mission Need dust protection Special cooling requirement
Imaging	Gross physical properties of nucleus (size, shape, rotation, optical properties) Physical heterogeneity of nucleus Disintegration of surface of nucleus Navigation	Sensor: CCD (800 x 800) Wavelength range: 3000 - 10,000 A Spatial resolution/FOV: 2×10^{-5} rad/0.47 deg 7×10^{-4} rad/16 deg	Telescopes exist CCD's under development (vidicon fallback) Need dust protection
Radar Altimeter	Mass of Nucleus Supplements Imaging Objectives Navigation Surface properties of nucleus (dielectric constant; roughness)	Range: ≤ 50 m at 10^3 km Velocity: ≤ 1 m s^{-1}	Current technology adequate

Table 4-2. Primary Measurement Objectives and Capabilities of Typical Instruments for Rendezvous (contd)

INSTRUMENT	PRIMARY MEASUREMENT OBJECTIVES	DESIRED INSTRUMENT CAPABILITIES	FLIGHT INSTRUMENT DEVELOPMENT STATUS
IR radiometer	Temperature and emissivity of surface of nucleus Thermal inertia of surface of nucleus	Wavelength range: 10 - 100 μm Resolution: ~1 - 10 μm FOV: ~10^{-3} rad	Good instruments exist Cooling problem Need dust protection
Orbital X-ray Fluorescence	Elemental abundance ratios for certain non volatiles (Al, Si, Mg, Ca, Ti, Fe) Relationship to meteorites	Energy range: 0.5 - 9 keV	Good instruments exist Cooling problem for detector
Dust Particle Counter and Analyzer	Dust flux and mass distribution Assessment of dust hazard Dust composition Charge	Velocity range: >10 m s^{-1} Mass Threshold: 10^{-13} g m/Δm: ~100	Need to decrease velocity threshold by 1 or 2 orders of magnitude Need to increase mass resolution by order of magnitude (if used in composition mode)
Collected Dust Analyzer	Elemental abundance ratios for certain non volatiles Relation to meteorites	1) α-scattering/X-ray fluorescence; dust sample volume: ~0.1 cm^{-3} 2) SEM-EDX type; only individual particles need to be collected	Dust collector needs study and development 1) Sensors and analyzers proven 2) Development needed
Landed Science	Temperature of surface (calibration of IR radiometer?) Surface strength Experience/exploration	1) Accelerometer 2) Thermal sensor 3) Imaging adapter 4) Anchor 5) Etc.	1) Good instruments exist 2) Good instruments exist 3) Need study and development 4) Need study and development

Table 4-3. Relation of Typical Payload to Science Objectives

SCIENCE OBJECTIVE	INSTRUMENTATION
(1) Determination of chemical and physical nature of nucleus	Neutral mass spectrometer Imaging and radar Landed science X-ray fluorescence spectrometer Near-IR spectrometer IR radiometer UV spectrometer Collected dust analyzer Dust particle counter and analyzer Magnetometer
(2) Characterize the physical evolution of the nucleus during its passage by the sun	Imaging and radar Near IR spectrometer UV spectrometer Neutral mass spectrometer IR radiometer Dust particle counter and analyzer
(3) Characterize the evolving chemical and physical nature of the atmosphere, ionosphere, and dust envelope	Neutral mass spectrometer Thermal ion spectrometer Electron spectrometer Ion mass and velocity spectrometer Magnetometer Plasma wave analyzer UV spectrometer Imaging Dust particle counter and analyzer Landed science
(4) Characterize the interaction of a comet with the interplanetary plasma and the origin and physical nature of comet tails	Ion mass and velocity analyzer Magnetometer Plasma wave detector Electron analyzer Thermal ion spectrometer

One of the fundamental problems concerning the formation of the solar system has to do with the process of building up macroscopic objects from microscopic grains and crystals of condensate. Specific questions include:

(a) Was there a preferred scale during the formation of small blobs of icy and rocky materials? Were these blobs of ice and rock formed separately (heterogeneous accretion) or together (homogeneous accretion)? One suspects that the relevant scales are probably 1-10 cm.

(b) Goldreich and Ward suggest that accretion proceeds rapidly from grains (and sub-blobs?) to pre-planetesimals on the scale of 10-100 meters. These pre-planetesimals are supposed to later agglomerate into larger planetesimals and eventually, in many cases, into planets. Did this really happen? And are there preferred scales in the accretion process?

Since the surface of an active comet provides the only accessible sample of unaltered accreted material (unaltered by internal heat and largely unaltered by external impacts since the surface remains youthful by sublimation) studying such a surface at high spatial resolution provides our best hope of determining answers to the above important questions.

The study of the most primitive carbonaceous chondrites can at best yield an answer to part of Question (a), since such meteorites do not contain icy material. Meteorites are too small to provide an answer to Question (b). A rendezvous with a highly primitive asteroid might provide a partial answer to (b), but the record will probably have been somewhat confused by later impacts.

Thus, testing of the Goldreich-Ward scheme requires imaging of a cometary nucleus with a resolution element about one-tenth the critical scale size (10 m). In other words, to answer Question (b), we need 1 m resolution.

To study the accretion of "sub-blobs" (Question (a)), a resolution about 10-100 times finer is required.

2. Measurement Objectives and Typical Characteristics of a Tail Probe

Table 4-4 indicates a typical payload for the tail probe. The probe concept, which we envision as being similar to an early IMP spacecraft, has not been analyzed in detail, but we expect a total mass requirement of less than 55 or 60 kg if no on-board propulsion is carried and ~100 kg if the tail probe has a few hundred m s^{-1} maneuver capability. Figure 4-1 is a sketch of a possible tail-probe configuration.

In the case of the ion drive mission, the tail probe would be deployed just after rendezvous with a $\Delta v \sim 250$ m s^{-1} and would fly a ballistic trajectory which passes through the tail as the comet reaches perihelion (Fig. 4-2). For the sail mission, the probe could possibly be carried into the tail by the sail after rendezvous (Fig. 4-3). In either case, the velocity relative to the nucleus remains low at about 1 km s^{-1} and insures a reasonably extended observing time within the tail. The measurement objectives of the tail probe are as follows:

(a) To determine the detailed structure of the tail; to measure the tail properties such as dust composition, ion abundances, ion and electron velocities, temperatures, and densities, magnetic field characteristics, plasma drifts, turbulence spectrum, etc.

(b) To identify the important dynamical phenomena that develop in the comet tail such as acceleration and diffusion processes, plasma instabilities, field line merging and "fireballs," internal shocks, field-aligned currents and anomalous resistivity, sub-storm phenomena, viscous effects associated with wave-particle interactions, etc.

(c) To relate the variations in the observed tail phenomena to changes in:

(1) The distance of the comet from the Sun.

(2) Solar wind input conditions, and associated variations in the coma and nucleus.

Table 4-4. Tail Probe — Typical Payload

INSTRUMENT	MASS, kg	POWER, w	DATA RATE, bps	HERITAGE	COMMENTS
Magnetometer	2.7	5.8	4	ISEE-B (Actual)	Magnetometer mounted on boom.
Plasma Wave Detector	4.3	3.1	6	ISEE-B (Actual) (2.9 kg plus 1.4 kg for 30 m tip-to-tip antenna with motor)	Search Coil on boom. Short electric antenna on boom. "Long" antenna body-mounted. 2.9 kg includes electronics, short electric antenna, search coil, and pre-amps.
Plasma Probe + Mass Analyzer	9.0	4.0	7	New: Based on various JOP proposals.	Must have capability to measure electrons, protons in solar wind, sheath region, and comet tail, plus capability for mass analysis in the tail region.
Dust Impact Counter and Analyzer	5.0	10.0	3	Helios (type)	May require time-sharing to meet a reduced power budget.
TOTAL	21.0	22.9	20		

3. Typical Payload for Flyby Missions

Not all of the instruments included in Table 4-2 would be retained for a flyby mission as a result of either insufficient sensitivity due to the short observation time available or the uncertain distance of passage from the nucleus. The following instruments (with effectively the same measurement capabilities as in Table 4-2) would be included in a typical flyby payload:

(a) Neutral mass spectrometer

(b) Thermal-ion mass spectrometer

(c) Ion mass and velocity analyzer

(d) Magnetometer

(e) Plasma wave detector

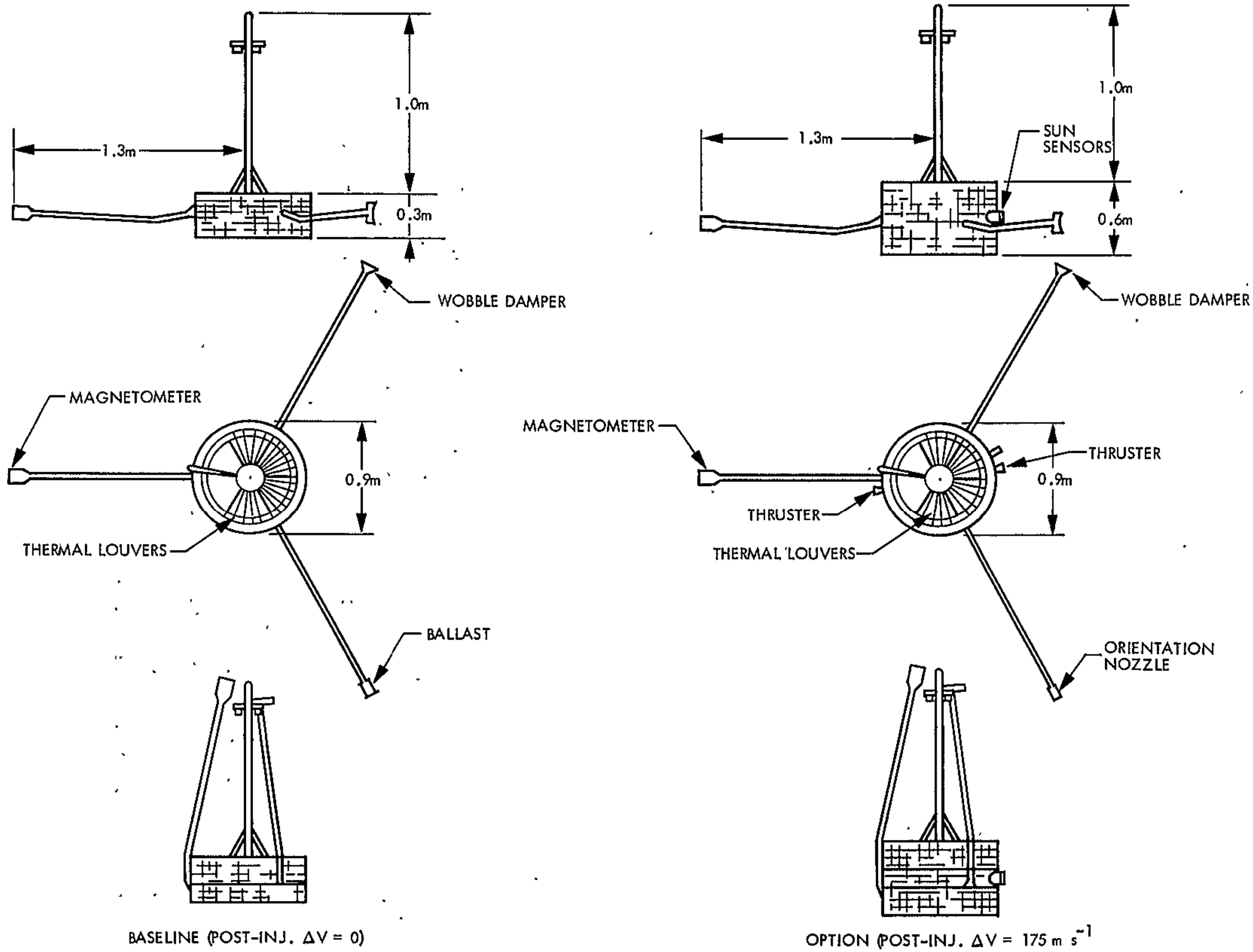

Figure 4-1. Typical Tail Probe Configurations

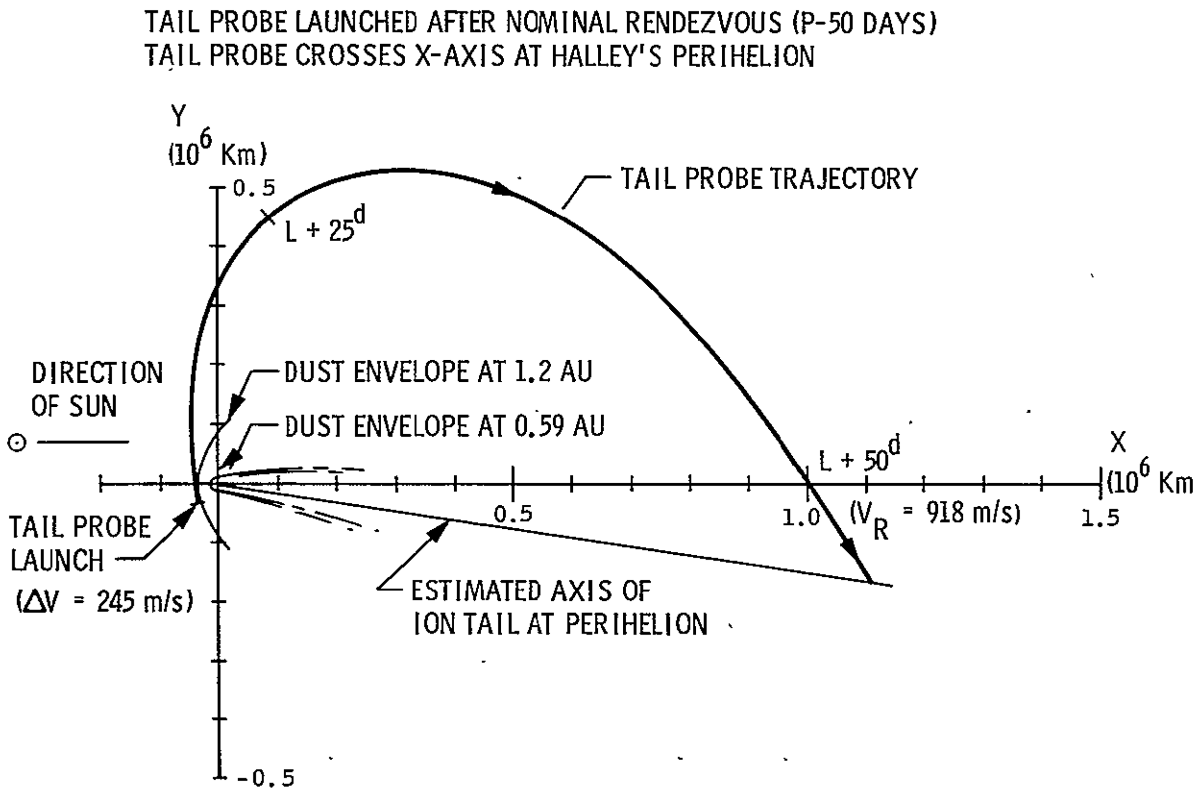

Figure 4-2. Halley Tail Probe Trajectory (Ion Drive Mission)

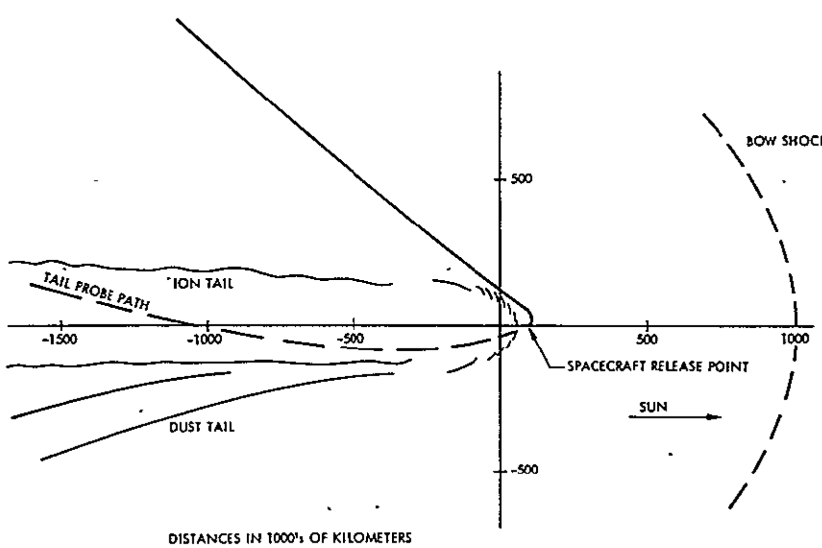

Figure 4-3. Solar Sail Exploration of Tail Region

(f) Electron analyzer
(g) UV spectrometer
(h) Imaging
(i) Dust counter and impact analyzer

Total weight, power and data rate characteristics would be roughly 76 kg, 80 w and 104 kbps respectively.

In the case of a flyby mission the spatial resolution of the imaging system will probably be limited to several 10's of meters at best, and the coverage will be limited; the mass spectrometer sensitivity will be reduced by the higher relative velocities and limited integration time; and any experimental landing capability will be lost. Only in the case of the impact analysis of dust does the flyby situation improve over that at rendezvous.

The relationship of measurement capability to the science objectives is drastically changed from the situation outlined in Table 4-3: for a flyby, the scientific emphasis is on objective (4) and a few points from (1) and (3).

4. Typical Payload and Measurement Objectives for a Lander Mission

Our view of a possible lander-specific payload is shown in Table 4-5. Surprisingly, the total scientific payload weight is less than that of the rendezvous payload yet the amount of landed science that can be done seems very substantial. The particles-and-fields complement is basically the same as that for a non-landed mission, and the opportunity to use these instruments is probably almost as great as in the case for a rendezvous mission.

The principal saving in weight is made by omitting one telescope and several remote sensing instruments (UV, IR, etc.) from the payload described in Table 4-1. We realize that this approach may be controversial and warrants more detailed study than we have been able to give it.

Table 4-5. Typical Payload for a Comet Nucleus Lander

1. CCD Camera System	20 kg
2. Neutral Mass Spectrometer + some separations chemistry	15
3. Dust component analysis: either, Alpha-proton-XRF + sample arm, or combined pulsed neutron activation	(7) (9)
4. Magnetometer + boom	12
5. Plasma wave detector	5.5
6. Electron/solar wind analyzer	9
7. Thermal ion mass spectrometer with retarding potential analyzer	5
8. Dust impact counter	2.5
9. Seismometer/gravimeter	9.5
10. Accelerometer	LN*
11. Temperature profile (10 thermocouples)	LN*
12. 75-year passive particle detector	LN*
TOTAL	85.5 to 87.5 kg

*Lost in the noise

C. MISSION HAZARDS

Among all the hazards faced in a cometary mission, the one which needs most comment here involves the anticipated dust flux.

1. Slowly Moving Dust: <1 km/s (rendezvous situation)

Dust particles <20 μm in diameter will probably stick to and change the properties of any surfaces they hit.

If transparency, conductivity, or porosity of the surface is needed, one may expect troubles. Figure 4-4 gives estimates of the time taken to cover 30% of a surface directly exposed to the expected dust flux near Comet Halley as a function of distance from the Sun and the nucleus. It is assumed that the spacecraft is at rest relative to the nucleus. Unless the hazard has been severely overestimated (which is a possibility), forays even to 100 km from the nucleus must be kept to a short duration relative to the total exploration time. Approach to within 10 km may need to be delayed to very large heliocentric distances (3 - 5 AU). On the other hand the spacecraft should be able to stay in the 10^3-10^4 km range (imaging resolution ~20 - 200 m) almost indefinitely. The dust model (Appendix A) on which these calculations rest has a cutoff at a diameter of 0.9 μm. As Sekanina has pointed out, this cutoff may not really exist. If the cutoff were at 0.1 μm rather than 1 μm, an extrapolation of the data in Appendix A shows the rate of dust accumulation would be three times faster than that shown in Figure 4-4.

Slowly moving dust particles >100 μm in diameter are expected to bounce off surfaces, perhaps producing damage at the impact point. The largest

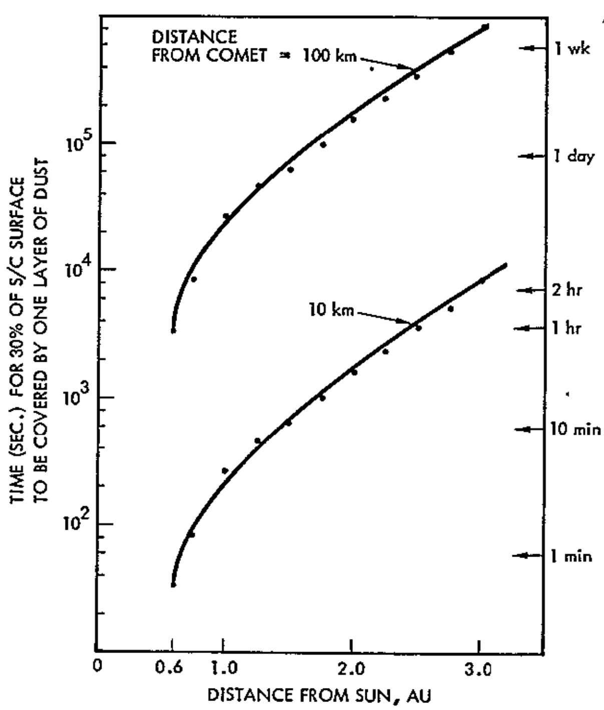

Figure 4-4. Dust Coverage

particles that are expected to be ejected from Halley are of the order of 5cm in diameter at 1 AU heliocentric distance, but these should be quite rare and move very slowly.

2. Fast Moving Dust: >3 km s^{-1} (Flyby Situation)

These particles are extremely dangerous for sensitive surfaces like lenses, solar panels and perhaps experiments. Impacts will produce craters (pits) which are from 2-5 times larger in diameter for silicates and glasses and up to 10 times larger for metals than the impacting particle itself. Crater depths are generally half of the crater pit diameters. Silicates and glasses also show a spallation zone (zone of expelled material) surrounding the impact pit. The diameters of these spallation zones are up to 5 times the pit diameters (depending on impact speed). Particularly for lenses and solar panels this is an important hazardous effect.

Fast particles hitting solids also produce secondary ejecta particles, a plasma cloud, and impact light flashes. These secondaries may affect sensitive experiments like mass or optical spectrometers. All these effects have been studied and measured in the laboratory. Quantitative results can be provided.

3. Possible Solutions for the Rendezvous Situation

The dust hazard outlined could seriously affect both the spacecraft systems and the scientific instruments.

As far as the spacecraft is concerned, there seem to be no fundamental problems involved. Stabilization, navigation, and thrusting of the spacecraft can be achieved regardless of the cometary environment. Dust coating of the large solar arrays on the ion-drive system will probably not be a major problem because (a) the power required for maneuvering is only a small fraction of that available after rendezvous and thus a fairly large degradation of the efficiency of the arrays can be tolerated, and (b) the arrays can be

rotated to a feathered or edge-on position to decrease their cross-sectional area relative to the dust flux. Dust particles will probably punch holes in the sail. The decision of when to drop the sail and switch to chemical propulsion can be made in real time. The nominal plan is to jettison the sail at the rendezvous point approximately 10^5 km sunward of the comet. As far as scientific instruments are concerned, we anticipate that special inlet configurations will have to be developed for mass and ion spectrometers (perhaps with the loss of some capability such as the ability to detect free radicals with the neutral mass spectrometer until late in the mission) and that special devices or techniques will be required to protect instruments with high performance optical surfaces. In any event the options to be considered before flight involve at least the following:

(a) Develop means to protect exposed surfaces and inlets from dust contamination and/or

(b) Develop an overall constraint on the total integrated flux that the spacecraft and its instruments should be exposed to during various phases of the mission.

Finally, in view of the fact that our knowledge of the magnitude of this hazard is uncertain, a highly adaptive mission operation strategy should be planned in order to respond quickly and advantageously to the actual situation found at the comet.

4. Interference from the Sail and Ion Drive Propulsion Systems

Both of the new propulsion systems are sources of interference to the scientific experiments on a comet mission. We believe, however, that proper technical design and sequencing of operations will allow all the experiments included in our typical payload to be carried out successfully.

a. Ion Drive. The very nature of the ion-drive propulsion system implies enormous potential for electromagnetic interference. However, it appears to be a simple matter to turn the thrusters on and off, and when they

are off, there seems to be no reason why the environment of the instruments should not be as quiet as in a conventional spacecraft system. Because of the powerful magnets in the ion engines, it will probably be necessary to supply a long boom for instruments such as the magnetometer that require low background fields. A boom approximately 18 m long is required to reduce the field to 0.1 γ; a somewhat shorter boom could be used with the dual magnetometer technique to monitor the spacecraft field. The potential on the solar cell arrays should not present a problem. Protective covers may have to be used to prevent accumulation of mercury on sensitive surfaces during cruise, although studies in progress seem to indicate no problem there either.

When the thrusters are on, we can expect interference with the local magnetic field and the generation of plasma waves. However, this "interference" might be used to advantage to yield some interesting results concerning the rate of thermalization of ion beams in the solar wind and the plasma instabilities involved. When the spacecraft is in regions of low density where the Debye length is long, the trajectories of ambient ions and electrons may be affected by the electric potentials (200 to 400 V) on the solar arrays. Since the orientation of the spacecraft is determined by the thrust vector direction, some problems may be experienced by instruments that wish to view specific directions (e.g., the comet) during thrust periods. Finally, all instruments can expect temporary electrical interference as a result of occasional arcing in the ion drive motors. We conclude that there will certainly be significant degradation of the scientific observations when the ion drive vehicle is thrusting, which is most of the time during cruise and some of the time after rendezvous. However, we are assured that it is a simple matter to shut down the thrusters for short periods of time and that straightforward mission and trajectory designs should allow acceptably long measurement periods in free fall.

The nature of the ion drive system must be taken into careful consideration while developing an exploration strategy at the comet. The engines cannot operate at pressures above 10^{-5} torr (~20 km from the nucleus

at perihelion) and the enormous solar arrays, which will be extended throughout cometary exploration, could experience significant aerodynamic forces.

The ion drive system also has a number of advantages over a conventional system. The neutralizer, for example, could be used to vary the spacecraft potential to ensure the observation of all ion species and electrons. Also, the propellant used for ion drive is mercury, which is of less scientific interest in the study of comets than are the exhaust products of conventional propulsion systems.

b. Solar Sail. Electrical interference from the solar sail appears to be minor, although a full assessment has yet to be made. The solar sail is nonmagnetic. The heliogyro blades are each 8 m wide by 7 km long. Thus at 0.25 AU, the Debye length is of the same order as the panel width, which makes theoretical analysis of the interaction of the sail with the solar wind difficult. The electric potential of the back (dark) side of the blades should be between the 500 V expected for the extreme case of complete screening of the ion current (width $\gg$ Debye length) and the 20 V expected if the front and back sides of the sail material were electrically shorted. Preliminary laboratory studies indicate that very thin Kapton film may be very "leaky" electrically and thus provide an appreciable amount of shorting. The nearest points of the blades are 175 m from the spacecraft. Possibly of greater concern than the sail itself are the mesh blade supports which must be electrical insulators in order to be rf transparent. These supports are separated from the spacecraft by 8 m booms.

Questions of the loading of the solar wind by sputtered sail material and the excitation of plasma waves by the interactions of the solar wind with the sail need further investigation. However, no source of unsurmountable interference with solar wind measurements is now obvious.

The sail presents a minor viewing problem in that approximately 2 deg is blocked during part of each heliogyro spin period. There is no obscuration for 4 or 5 s out of every 90 s. The sail could be tipped if this obscuration

occurs at a critical place and time. In addition, the mesh on the brace of the heliogyro forms a partial obstruction, although it is nearly transparent. Triangular regions of mesh visibility occupy a small portion of the viewing for about one-third of the spin period.

A possible source of interference is the chemical propulsion system which would be used to maneuver about the comet after the sail is dropped. Conventional propulsion systems usually use hydrazine (NH_2NH_2) with water. The decomposition products of this monopropellant are all scientifically interesting species to search for in a comet. However, we expect that, because of the strong outflow of gas from the comet, propellant contamination close to the nucleus will disperse within seconds. A cold gas system (krypton) could be used instead of hydrazine but is not advised because of a large weight penalty. Such a system is practical for attitude control, either directly or to unload momentum wheels.

D. SOME COMPARISONS OF THE SOLAR SAIL AND ION DRIVE RENDEZVOUS MISSIONS TO HALLEY'S COMET

The chief characteristics of the nominal rendezvous missions which we have reviewed are listed in Table 4-6.

The chief factors which the two missions have in common are:

(1) Both propulsion systems have adequate scientific payload delivery mass, power capability, and maneuvering capability for a rendezvous mission.

(2) Both types of nominal missions rendezvous with the comet at a period when the comet is very active.

(3) Both nominal missions appear to have a reasonable range of rendezvous opportunities for the nominal launch date. To a limited degree, the effects of deterioration of performance of the propulsion units during flight can be mollified by changing the rendezvous distance from the Sun (Sail: 0.9 - 4 AU, postperihelion; Ion Drive: 60-10 days (1.33 to 0.63 AU) preperihelion).

Table 4-6. Chief Characteristics of the Sail and Ion Drive Nominal* Missions

CHARACTERISTICS	SAIL	ION DRIVE
Total Mass (20% contingency included)	4856 kg	4552 kg (including 2357 kg propellant)
Spacecraft Mass	861 (including 179 kg chemical propellant)	392 kg
Science Payload Mass	124 kg	124 kg
Spacecraft Electrical Power	2 RTG's	Solar Electric
Δv Capability at Comet	500 m s^{-1} (chemical)	Large: Keeps ion propulsion unit
Navigation Requirements (time before rendezvous)	On-board optical (R-60 days)	On-Board optical (R-60 days)
Characteristic Acceleration	1.05 mm s^{-2}	0.4 - 1.0 mm s^{-2}
C_3	12 km^2 s^{-2}	17.5 km^2 s^{-2}
Rendezvous Time	34 days postperihelion	50 days preperihelion
Rendezvous Distance	0.92 AU	1.2 AU
Mission termination distance	≥4 AU	3-4 AU
Launch Date	November 1981	May 15 - June 20, 1982
Flight Time to Rendezvous	~1595 days	128? days
Minimum Solar Distance	0.25 AU	0.59 AU (perihelion)
Minimum Sun-Earth-Spacecraft Angle after Rendezvous	always large	6.6°
Phase Angle of Nucleus on Final Approach	~142° (crescent phase)	~58° (gibbous phase)

*As of 7/11/77

(4) Both propulsion systems provide adequate backup rendezvous capability to Comets Encke or Giacobini - Zinner.

(5) In both nominal missions the rendezvous extends to large heliocentric distances from the Sun to allow close scrutiny of the nucleus even if a major dust hazard exists near perihelion.

The principal factors in which the two missions differ are:

(1) The rendezvous time and the time available for maneuvers. The ion drive rendezvous occurs 50 days before perihelion, which leaves ample time for assessing the cometary environment near the nucleus, for developing the best mission strategy, and for permitting detailed study of processes occurring at the nucleus throughout perihelion passage. Since the solar sail cannot thrust toward the Sun, it cannot decelerate fast enough to make a pre-perihelion rendezvous; nominal sail rendezvous is approximately 34 days after perihelion.

(2) The appropriateness, from the science return point of view, of the approach trajectory. The ion drive approach is from the sunward side and can provide excellent measurements of the chief upstream features expected in the solar wind/comet interaction. Also, the phase angle of the ion drive approach provides superior observing opportunities for studies of the nucleus. Because the sail spacecraft must rendezvous after perihelion, its apparent approach to the comet is from the antisunward direction.

(3) The relative ease and lack of interference for carrying out measurements both during the cruise phase of the mission and after rendezvous. These factors have been discussed in Section IVC4.

(4) The probability of successfully landing on the nucleus and the ability to function after landing. The large solar arrays attached to the ion-drive spacecraft may make landing very difficult. Since the sail spacecraft uses radio-isotope thermoelectric generators as its source of power, it will not depend on a proper post-landing orientation with respect to the Sun in order to operate.

SECTION V
MISSION STRATEGY

A. IMPORTANCE OF ENCOUNTER DISTANCE AND MERIT OF PRE-PERIHELION ENCOUNTERS

To optimize the study of dynamic phenomena at the nucleus, ionization processes, gas phase reactions, and the generation of plasma tails it is important to encounter the comet at a heliocentric distance less than 1.5 AU. Encounters beyond this distance become increasingly undesirable because of the rapid falloff of activity and gas production with heliocentric distance (for example - the brightness of Comet Halley followed an $r^{-5.2}$ law on approaching the Sun in 1910). Also it is a matter of experience that only in a few exceptional cases are emissions from ions visible in cometry spectra outside 1.5 AU. Finally, it is also generally true that the full range of molecular species associated with comets are not generally visible in the spectrum of the coma unless the comet is within 1.5 AU of the Sun.

On the other hand, nucleus-intensive studies will be constrained by the level of cometary activity and associated hazards, such as the production of large quantities of dust. Such hazards can be expected to depend on the degree of activity, which is known to be a strong function of heliocentric distance. Thus, intensive studies of the nucleus from very close range cannot be carried out at small heliocentric distances and will probably have to wait until the distance reaches at least 1.5 AU outward bound from the Sun.

The two propulsion systems being considered for accomplishing a comet rendezvous mission have markedly different capabilities for encountering a comet. The solar sail is effectively constrained to postperihelion encounters while the ion drive is not. A preperihelion encounter would enhance the return from dynamic investigations since it maximizes the amount of high quality data at minimum heliocentric distance (and presumably maximum activity). A second factor of a pre-perihelion encounter is that it provides ample time to assess any hazards presented by the cometary environment and to implement an adaptive mission strategy. Finally, a preperihelion encounter provides a

superior trajectory for comet/solar wind interaction studies and minimizes the propulsion capability needed to deliver a probe into the plasma tail.

On the other hand, a preperihelion encounter probably does not enhance nucleus-intensive studies substantially since the hazards in the neighborhood of the nucleus will probably be too severe near perihelion to permit the desired close approach.

B. MISSION OPERATIONS STRATEGY

The mission operations strategy sketched out below is primarly conditioned by three factors:

(1) The range of scales at which cometary phenomena exist is enormous (up to 10^8 km).

(2) The nucleus, inner atmosphere, and plasma tail are <u>active</u> phenomena (i.e., we can anticipate unexpected and erratic phenomena).

(3) The magnitude of the dust hazard is very poorly understood.

The latter two conditions are particularly important since they imply that mission operations should be highly adaptive and capable of rapid response times ($\sim$1 day or less).

We recommend the following general mission operations strategy:

(1) Approach the comet, in the sunlit hemisphere if possible, emphasizing measurement of solar wind interaction phenomena and the dust hazard. Fig. 5-1 presents the sail and ion drive approach trajectories and shows that the latter is a better choice. The sail bow shock excursion which is illustrated is not considered a viable option since it implies a penalty of $\sim$40-50 days in the rendezvous time.

(2) Approach the nucleus slowly, and assess its large-scale activity (spacecraft-nucleus distance $\sim 10^3$-10^4 km).

(3) Deploy tail probe to ensure tail passage when main spacecraft is in the comet's ionosphere before the comet reaches 1.5 AU from the Sun.

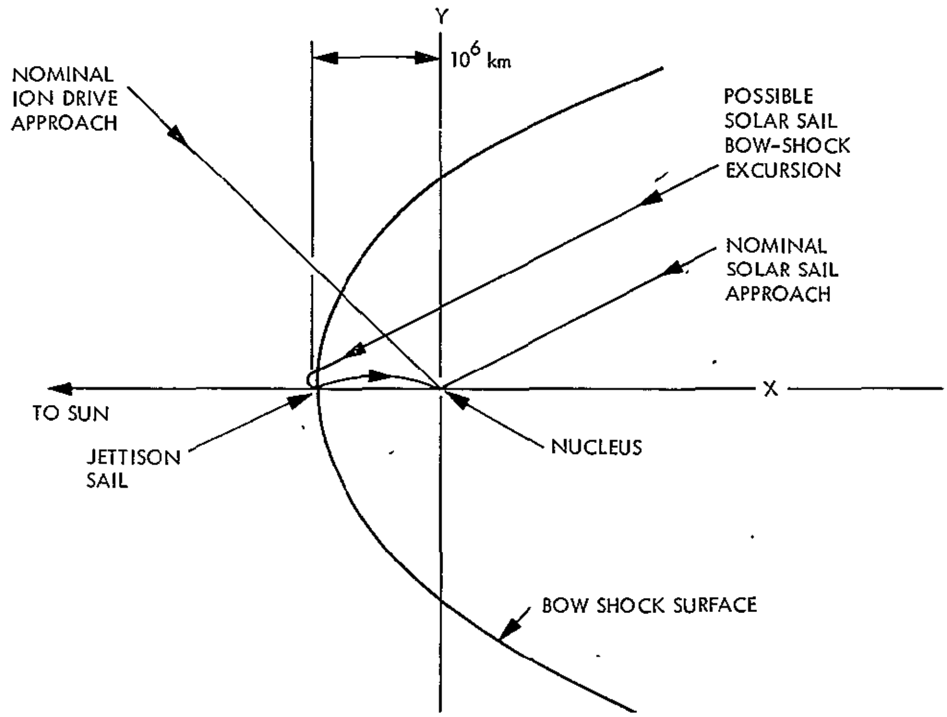

Figure 5-1. Characteristic Sail and Ion Drive Approach Trajectories

(4) Reconnoiter the cometary atmosphere and return to the nucleus when the cometary activity has decreased. The rate of approach would be determined by the level of activity as sensed by the dust detectors, the accelerometer, the imaging system, and the neutral and ion spectrometers. Examples of typical atmospheric maneuver opportunities are illustrated in Figs. 5-2 and 5-3. Note that the time scale for these maneuvers is generally measured in tens of days.

(5) Perform nucleus-intensive measurements (10-10^2 km spacecraft-nucleus distance). This phase is expected to occur when the comet is between 1 and 3 AU, depending on the magnitude of the hazards.

(6) Terminate mission by an experimental descent onto the nucleus. This is expected to occur between 3 and 4 AU.

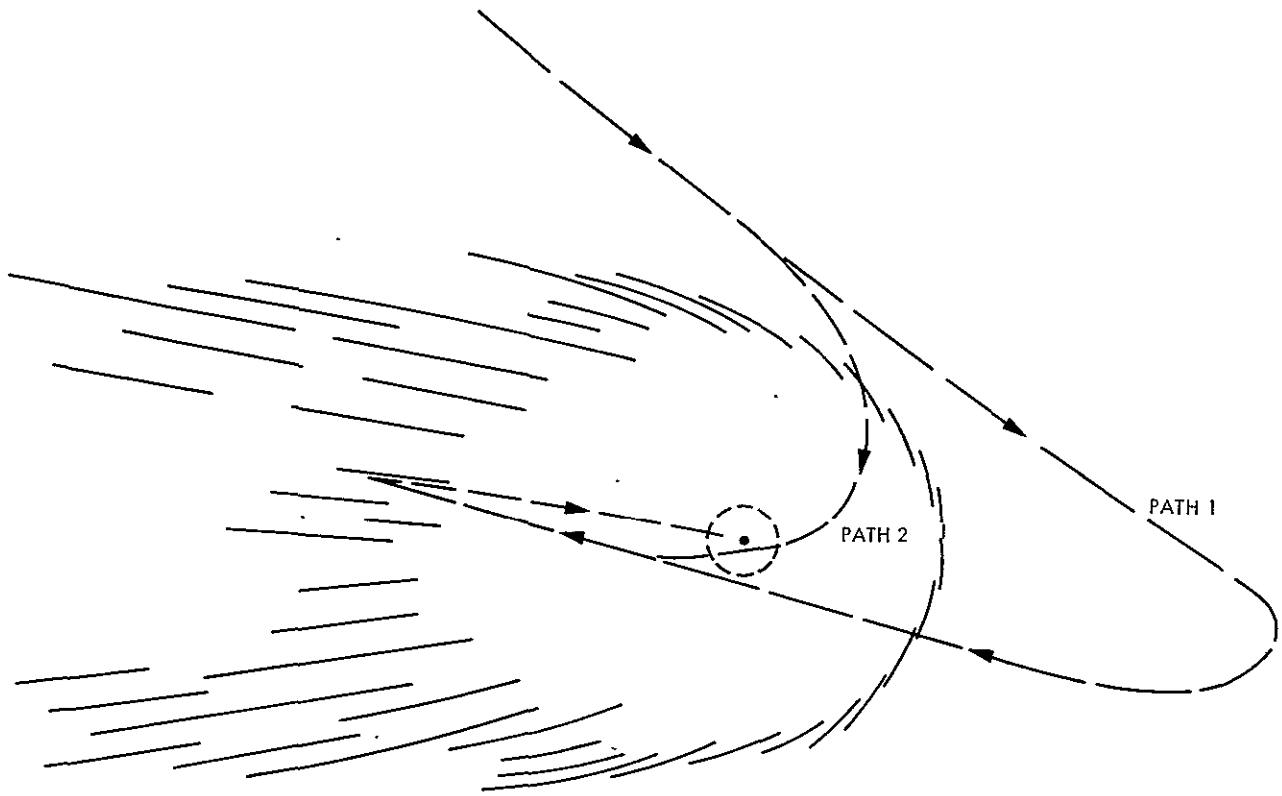

Figure 5-2. Two Possible Sail Approach and Atmospheric Reconnaisance Trajectories

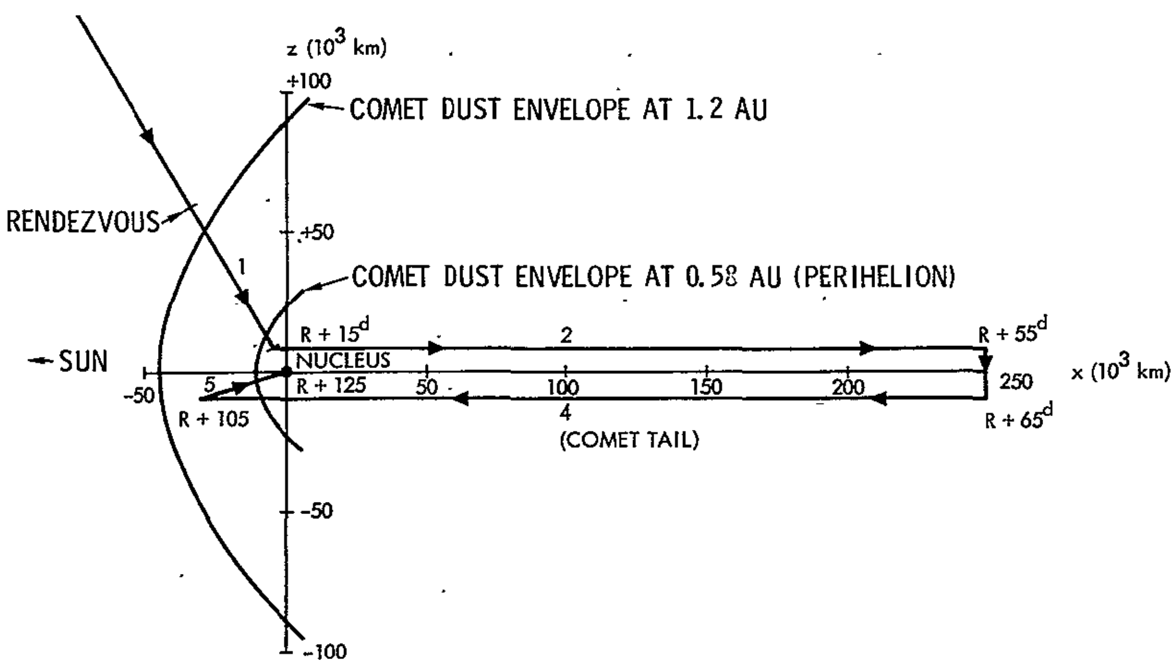

Figure 5-3a. Circumcomet Exploration Trajectory with Ion Drive Operating Continuously

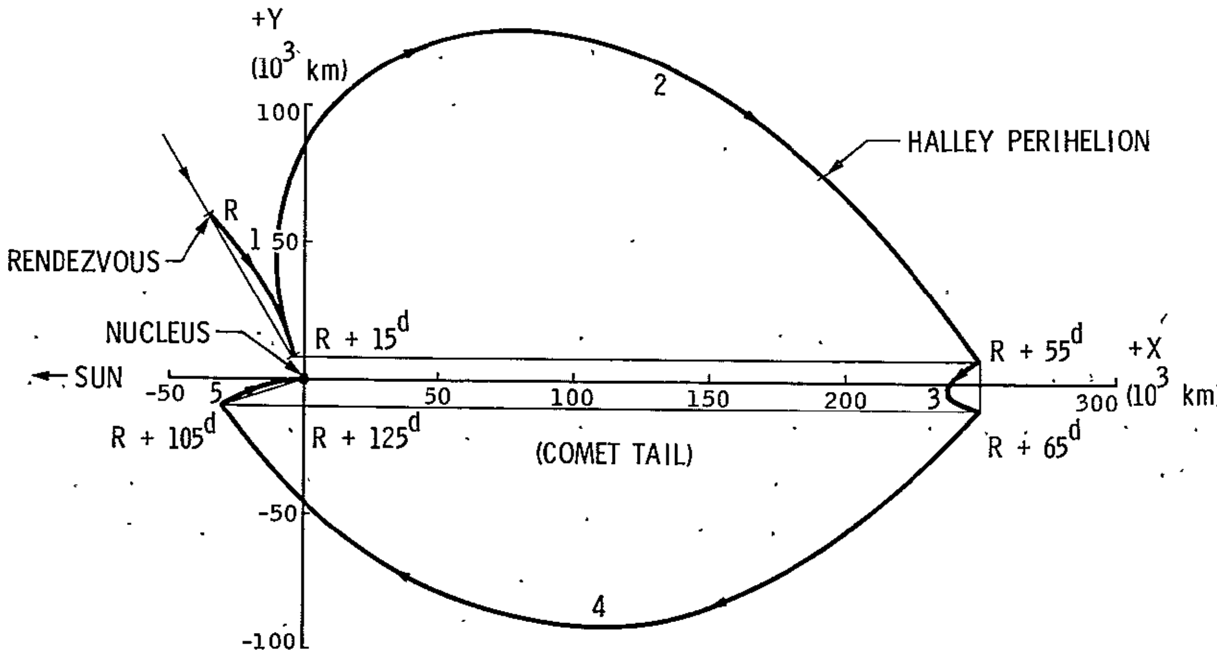

Figure 5-3b. Circumcomet Exploration Trajectory with Ion Drive Operating Only at the "Corners"

The above scenario is for a rendezvous mission. In the case of a lander-specific mission we add the following operations: on landing the spacecraft, drive a hollow spear some 1-2 meters into the nucleus to measure the gross meterial strength; an analysis period (up to 6 months) for atmospheric, surface and subsurface measurements then follows.

A landed payload could also carry materials through the outer solar system to register galactic cosmic ray tracks, perhaps a thermometer which records the minimum temperature, or other yet-to-be-conceived passive, cumulative experiments; this package to be retrieved in 2061 AD at the next apparition of the comet.

C. MISSION TERMINATION

The nominal mission should be terminated only after the scientific objectives relating to the nucleus have been achieved. Since cometary activity is known to occur out to heliocentric distances of 3 AU or greater, the minimum requirements appear to be the order of one week's observation time at a distance of 3 AU.

It is also important to consider the mode of termination of a rendezvous mission. A good deal of knowledge about comets can be obtained only by landing on the nucleus or even returning a sample to Earth. It is clear that it is our ignorance of the mechanical and physical nature of the nucleus and not technical capability that is the major impediment to a mission that includes a soft landing. Thus it must be an important part of the first comet mission strategy to adequately set the stage for follow-on missions that will involve landing. In the case of a rendezvous mission the CHSWG feels that mission termination should involve a descent onto, or docking with, the nucleus in order to examine its structure at the very highest resolution and to roughly establish its mechanical strength.

The CHSWG is aware that treating this maneuver as a prime mission objective would imply some very large cost increment (perhaps double the cost) and would remain, even in view of the weak gravitational field of the comet, a risky business. Nevertheless, we feel that important gains can be obtained (e.g., technical experience, estimates of surface strength, surface structure at very small scales) even with a landing that allows no further instrumental operation. We, therefore, conclude that the mode of termination of a rendezvous mission should be to make an attempt at landing, but this should not be included among the prime mission objectives.

D. THE ROLE OF EARTH-BASED OBSERVATIONS AND OBSERVATIONS FROM OTHER SPACECRAFT

Expected Developments in Cometary Science as a Result of Ground-Based Work in the Next Decade

In the next ten years we anticipate that some 3 or 4 bright comets suitable for detailed physical observations will pass through the inner solar system. It seems almost certain that there will be no major breakthrough in our understanding of the cometary nucleus unless a very close passage to the Earth occurs, which is a remote chance. We can expect, with proper support, some substantial developments in our understanding of physical processes that may be occurring in the inner cometary atmosphere and ionosphere. In addition we expect that advances in observational spectroscopy will lead to the discovery of new molecules in comets and will clarify the situation with respect to the "parent" molecules somewhat.

2. Observations Supplementary to a Halley Mission

We have identified three areas which are particularly important:

(a) Early retrieval of the comet at great distances from the Sun either with large ground-based telescopes or the Space Telescope. We estimate that the comet could be retrieved (with luck) even as early as the beginning of 1984 when the comet is near 22 mag. This would be very important from two points of view: first, it would allow a very close assessment of the comet's orbit, and second, accurate brightness measurements so far out could lead to the best estimates yet of the size of the nucleus. Both of these factors would be very important in planning the final mission strategy.

(b) Physical observations from the Space Telescope can be expected to provide invaluable supplementary data to the observations made <u>in situ</u> by the rendezvous spacecraft. At closest approach to the Earth (April 11, 1986) the wide field camera and faint object spectrograph system on the ST should be capable of resolutions of

100 km or less. This scale is substantially less than the scale ($\sim 10^3$ km) over which most of the active atmospheric and ionospheric processes occur near to the nucleus. Thus the Space Telescope instrumentation should be able to achieve the "big" view of the activity that is taking place while the Halley spacecraft is concerned with detailed processes on a local scale. This is ideal observational synergism.

(c) The range of scales in comets is enormous and so, just as the Space Telescope instrumentation will provide a more extensive view of cometary activity than the spacecraft at rendezvous, ground-based systems (wide field cameras, spectroscopic systems of all types) will provide an important record of phenomena at even larger scales.

Clearly, great efforts will be required to properly coordinate these ground-based and Space Telescope efforts with those of the space probe.

E. QUARANTINE

During a comet's passage through perihelion the temperature of its surface rises from what is normally a very low value and causes the release of massive amounts of surface material which is lost to space. It is estimated that some 1-5 meters of the surface of Comet Halley is stripped off during each passage through perihelion. Furthermore, lifetimes of comets are relatively short and large numbers of comets exist; thus, contamination of a single comet is less serious than contamination of a major planet.

With this environment in mind, the CHSWG sees no need for any biological quarantine or sterilization for a comet mission.

SECTION VI
BACKUP AND FOLLOW-ON MISSION POSSIBILITIES

It is the belief of this working group that cometary missions are of great importance in solar system studies as well as quite significant in their own right. Should some technical or financial roadblock prevent our first choice of a rendezvous mission to Comet Halley, a cometary program should nevertheless continue, its form being dependent upon available delivery systems.

A. BACK-UP STRATEGY FOR THE COMET HALLEY RENDEZVOUS MISSION

The CHSWG considered only the general problem of fallback strategy for the case in which it becomes clear <u>well before launch</u> that it is not possible to achieve the nominal rendezvous mission. Two clear types of option were identified: one in which the strategy kept Halley as the target with a flyby option backing up the rendezvous and a second which kept a rendezvous mission with another comet backing up Halley. The latter option, which the CHSWG overwhelmingly preferred, involves maintaining rendezvous with Halley until some agreed upon distance from the Sun, postperihelion, and then switching to a rendezvous with Comet Encke, Comet Ciacobini-Zinner, or some other available short-period comet. Finally, if the capability for any rendezvous disappears altogether, a relatively slow flyby should be planned to Halley or, if this is not possible, some other available periodic comet. In connection with this strategy, we note that a science payload chosen for a Comet Halley rendezvous should also perform excellently at an Encke or Giacobini-Zinner rendezvous; also, the distance from the Sun at which rendezvous with Encke or Giacobini-Zinner is targeted will be best determined after the actual mission's objectives and science payloads have been defined.

B. FOLLOW-ON MISSIONS TO A HALLEY RENDEZVOUS

The CHSWG has not discussed specific cases of follow-on missions. However, it is the belief of the group that a sample return mission to Comet Encke in 1990 or 1994 is a logical follow-on to a successful rendezvous with Comet Halley.

APPENDIX A

A FIRST STEP TO A PHYSICAL MODEL OF COMET HALLEY

Much of the material reported here is the work of Ray L. Newburn, Jr. and D.K. Yeomans of the Jet Propulsion Laboratory

APPENDIX A

A FIRST STEP TO A PHYSICAL MODEL OF COMET HALLEY

Modeling a comet is an uncertain undertaking which often requires gross extrapolation from the observations. At the time of the last appearance of Comet Halley in 1910, astronomy was a largely qualitative science. Photographs and spectra were taken on uncalibrated plates, and magnitude estimates varied with equipment and observer. In the limited time available for this study it was decided to tie the model of Halley to the best possible estimate of its light curve and use other comets for quantitative calibration. Recommendations for an improved model conclude this appendix.

Copies were obtained of all papers on Halley referenced in the Astronomischer Jahresbericht from 1909 through 1917. Yeomans extracted all brightness observations, applied Morris aperture corrections, and produced a model light curve. Newburn produced a theoretical functional relationship between the observed brightness, the apparent coma size of a comet, and its gas and dust production rates. By making a number of simplifying assumptions (e.g., the brightness is an instantaneous function of the production rate; opacity effects can be ignored; the dust size distribution function is the same as determined for C/Bennett; the relative composition of molecules fluorescing in visible light is the same as in Comets Encke and Bennett; etc.) the unknowns in the relationship were evaluated.

Newburn then produced tables of gas and dust production as a function of heliocentric distance. Deriving particle velocities from the expressions of Delsemme and Miller, he produced tables of particle density and flux as a function of distance from the nucleus.

A. THE PHYSICAL STRUCTURE OF THE NUCLEUS

All information in Table A-1 is based on the concept of a single-body, icy conglomerate nucleus and is derived indirectly (essentially from photometric considerations) either from observations of Halley at its 1910 apparition or from observations of recent comets (particularly Comet Bennett, 1970 II) which

Table A-1. Estimate of Physical Properties of the Nucleus of Comet Halley

radius	$\sim$2.5 km
density	$\sim$1 gm cm^{-3}
mass	$\sim 6.5 \times 10^{16}$ gm
escape velocity	$\sim$2 m s^{-1}
rotation	$\sim$ slow (range $\sim$ 4 to 24 hr), direct
shape	irregular
mechanical strength	$\leqslant 10^5$ dynes cm^{-2}; easily fractured
albedo	0.4
structure	very inhomogeneous
magnetic field	unknown; probably zero
surface temperature	200°K near 1 AU, varies as $r^{-0.07}$

showed strong similarities to Halley. The uncertainties are estimated to be a factor of 10 or less for the linear dimensions, density, rotation period, surface temperature and thermal emissivity; but more than a factor of 10 for the mass and mechanical strength. The shape of the nucleus is entirely unknown, but believed to be irregular.

H_2O is expected to be the major component of the volatile fraction. This assumption is supported by orbital calculations of the nongravitational forces by Yeomans, by the average rate of brightening with heliocentric distance, and by results from UV and radio observations of recent comets which show similar behavior.

B. THE CHEMICAL COMPOSITION OF THE NUCLEUS

Our only direct information comes from observations of cometary spectra; the supposition that there is a close analogy between cometary molecules and molecules found in dark nebulae; and finally a suspicion of a relationship between comets and carbonaceous chondrites, volatile rich samples returned from the moon, and micrometeorites. We do not review this complex subject here but note the important and detailed discussions of Delsemme ("The Volatile Fraction of the Cometary Nucleus" 1975, Icarus 24, 95) and of Brownlee, Rojan and Tomandl ("A Chemical and Textural Comparison Between Carbonaceous Chrondrites and Interplanetary Dust," 1976, Proc. IAU Colloq. 39, Lyon, France).

In very broad terms the nucleus is thought to consist primarily of a highly inhomogeneous agglomerate of water ice, more volatile ices, and siliceous rocks, with composition possibly similar to that of the carbonaceous chondrites. The rocks may have a wide range of sizes from submicron grains to substantial blocks (meters?). The ratio of the mass of rocky material relative to ices in Comet Halley probably is of the order of or less than one. Mixed in with the ices, probably at the molecular level and making up the order of 20% of the total mass, is a rich selection of complex H, C, N, O molecules (see Section C3 of Appendix A).

C. ESTIMATES OF THE COMPOSITION AND DENSITY OF NEUTRAL ATMOSPHERE OF COMET HALLEY

1. Production Rates of Neutral Molecules

No production rates for H_2O can be deduced from old 1910 spectra, and the only reasonable procedure is to make a comparison with a recent observed bright comet of the Halley type, like Comet Bennett, and make a guess in proportion to its reduced brightness; H_{10}:

	H_{10}	Production Rate at 1 AU
Bennett	4.5	3×10^{29} H_2O s^{-1}*
Halley (1986)	4.8	$1\text{-}2 \times 10^{29}$ H_2O s^{-1}

*(Keller & Lillie, 1974, Astr. & Ap. 31: 123)

Neutral molecules and atoms which have been positively detected in spectra of Halley are CN, C_3, CH, C_2, and Na (near perihelion). Delsemme estimates from published work done on these spectra that the following number densities may be appropriate at the 1986 apparition:

Molecules	Number Density (1 AU; 10^4 km from Nucleus)
H_2O	$\sim 10^5$ cm^{-3}
C_2	$\sim 10^3$ cm^{-3}
CN	$\sim 10^3$ cm^{-3}

2. Variation of Production Rate with Distance from the Sun

Table A-2 gives an estimate of the variation of the total production rate of molecules expected from Halley as a function of heliocentric distance based on the observed run of brightness. It has been assumed that the gas to dust mass production rates are equal and H_2O makes up 80 percent of the molecular production by number. Table A-3 gives our rough estimates of the expected density of H_2O as both a function of heliocentric distance and distance from the nucleus. With the observed exception of CN and OH which extend out to distances of 10^5 km from the nucleus, visible evidence of most other molecules is removed from the atmosphere over scales of a few times 10^4 km.

3. Compendium of Neutral Molecules Which Probably Exist in Cometary Atmospheres

Table A-4 contains a list, by mass, of neutral molecules and atoms that probably exist in the atmosphere of Comet Halley while it is within 1.5 AU of the Sun. The list is based on work reported in Delsemme (Icarus 24, 95, 1975) but also includes molecules more recently found in comets and in interstellar space. The aeronomy of these molecules is ill understood and we cannot even guess the variation of the populations of these molecules with changing heliocentric distance. However, we note that substantial sublimation of H_2O should be taking place even as far out as 4 AU; CN is often observed in comets to 3 AU; C_3 and N_2 are seen within 2 AU, C_2 within 1.8 AU and within

Table A-2. Estimated Variation of Molecular Production Rate in Halley with Heliocentric Distance

PREPERIHELION		POST PERIHELION	
DISTANCE, AU	PRODUCTION-RATE, $mol \cdot s^{-1}$	DISTANCE, AU	PRODUCTION $mol \cdot s^{-1}$
0.6	1.4×10^{30}	0.6	1.1×10^{30}
0.8	4.2×10^{29}	0.8	3.0×10^{29}
1.0	1.5×10^{29}	1.0	1.6×10^{29}
1.2	6.2×10^{28}	1.2	1.2×10^{29}
1.6	1.4×10^{28}	1.6	5.6×10^{28}
2.0	5.5×10^{27}	2.0	3.0×10^{28}
-	-	2.5	1.3×10^{28}
-	-	3.0	6.1×10^{27}
-	-	3.5	3.0×10^{27}

1.5 AU all other molecular emissions are usually present (P. Swings and L. Hazer, "Atlas of Representative Cometary Spectra," University of Liege).

4. Dust in the Atmosphere of Comet Halley

Halley appears to be a relatively dusty comet (strong continuum in the spectrum; dust tail; associated meteor showers). The dust/gas mass ratio cannot be an order of magnitude away from 1; it was perhaps 1.67 in Arend Roland and 0.50 in Bennett. We, therefore, assume it is 1 in Halley. A fair estimate for the uncertainty in this estimate is perhaps a factor of 5. The character of the particle-size distribution is unknown, but is believed to be proportional to (a^{-4} to a^{-5}) da, where a is particle radius. The cutoff on the side of small sizes is uncertain (the model takes the cutoff at 0.45 μm in radius); if 0.1 μm particles are abundant, the impact rate on dust detectors can go up by some two orders of magnitude compared to the present model! Sudden outbursts of dust are also a possibility. Dust particles are likely to carry a charge, perhaps ~+10 V in the tail.

Table A-3. Density of H_2O vs Distance from Nucleus*

DISTANCE FROM NUCLEUS, km \ HELIOCENTRIC DISTANCE, AU	PRE-PERIHELION			POST-PERIHELION				
	2.0	1.0	0.6	0.8	1.0	1.4	2.0	3.0
10	7.84×10^{9}	2.18×10^{11}	1.92×10^{12}	4.23×10^{11}	2.34×10^{11}	1.16×10^{11}	4.24×10^{10}	8.65×10^{9}
50	3.13×10^{8}	8.69×10^{9}	7.59×10^{10}	1.68×10^{10}	9.32×10^{9}	4.63×10^{9}	1.69×10^{9}	3.46×10^{8}
100	7.82×10^{7}	2.16×10^{9}	1.87×10^{10}	4.17×10^{9}	2.32×10^{9}	1.15×10^{9}	4.23×10^{8}	8.64×10^{7}
500	3.09×10^{6}	8.28×10^{7}	6.64×10^{8}	1.56×10^{8}	8.88×10^{7}	4.52×10^{7}	1.67×10^{7}	3.44×10^{6}
1,000	7.63×10^{5}	1.96×10^{7}	1.43×10^{8}	3.58×10^{7}	2.10×10^{7}	1.10×10^{7}	4.13×10^{6}	8.55×10^{5}
5,000	2.74×10^{4}	5.10×10^{5}	1.73×10^{6}	7.32×10^{6}	5.47×10^{5}	3.53×10^{5}	1.48×10^{5}	3.26×10^{4}
10,000	5.99×10^{3}	7.44×10^{4}	9.69×10^{4}	7.89×10^{4}	7.98×10^{4}	6.70×10^{4}	3.24×10^{4}	7.68×10^{3}

*The assumed loss mechanism is photodissociation with a lifetime at 1 AU $\tau_1 = 2 \times 10^4$ seconds. It also assumes all gas comes off as gas (no icy grains). Actually, half or more may be grains initially. And this is just H_2O, not all gasses. Other gasses can be scaled directly as their mixing ratio to water, if they have the same lifetime.

Table A-4. Neutral Species Possible in Comet Halley*

MASS	NAME	RELATIVE ABUNDANCE (log 10)	MASS	NAME	RELATIVE ABUNDANCE (log 10)
1	(H)	10	41	(CH_3CN)	7
2	H_2	?	42	NH_2CN	
3			43	HNCO	7
4	He	4	44	(CS,CO_2), $CH_3\cdot CH\cdot O$	7, 8, 7
5			45	$NH_2\cdot CH\cdot O$	6
6			46	$HCO\cdot OH$, H_2CS, NS,	
7				$CH_3\cdot CH_2\cdot OH$	7, 8
8			47		
9			48	C_4, SO	6, 6
10			49		
11			50		
12	(C)		51	$CH\cdot C\cdot CN$	6
13	(CH)	7	52	(Cr)	4
14			53	$CH_2\cdot CH\cdot CN$	
15	(NH)	7	54		
16	(O), CH_4, (NH_2)	10, 9, 7	55	(Mn)	4
17	NH_3, (OH)	9, 10	56	(Fe), C_4H_8	5, 6
18	H_2O	10	57		
19			58	(Ni)	4
20	Ne	2	59	(Co)	4
21			60	OCS, SiS, $HCO\cdot O\cdot CH_3$	5
22			61		
23	(Na)	7	62		
24	(C_2)	8	63		
25	$(C^{12}C^{13})$, C_2H	6	64	S_2, SO_2	8
26	(CN)	8	65	(Cu)	4
27	(HCN)	8	66		
28	(Co), N_2, (Si)	10, 9	67		
29	CH_2NH, NCO	7	68		
30	H_2CO, NO, C_2H_6	5	69		
31	CH_3NH_2	7	70		
32	S, CH_3OH	8, 7	71		
33			72		
34	H_2S	8	73		
35			74		
36	(C_3)	7	75	$NH_2\cdot CH_2\cdot CO\cdot OH$, HC_5N	5
37			76		
38			through	A range of complex	
39	(K)	6	250	organic molecules found	5 - 8
40	$CH_3\cdot C\cdot CH$, (Ca), Ar	7, 4, 4		in CI meteorites	

*( ) means that this species has been directly detected in comets. Relative abundances are rough estimates by number, normalized to log H_2O = 10. Delsemme's list has been supplemented by molecules found recently in interstellar space (B.J. Robinson, "Molecular Astronomy" Astron. Soc. Aust. Proc. 3, 12).

Tables A-5, A-6 and A-7 give the estimates of terminal velocity, concentration and flux as functions of particle size at various heliocentric distances.

D. THE IONOSPHERE OF COMET HALLEY

The only ions that have been positively identified in spectra of Comet Halley are CO^+ and N_2^+. Delsemme believes that H_2O^+ may be present in some of Bobrovnikoff's spectra. There seems no reason to doubt that ionic species observed in other bright comets will be present. These include CH^+, NH^+, OH^+, Ca^+, and CO_2^+. In addition, the theoretically important species H_3O^+ and HCO^+ should be present.

Available ionospheric models for comets are very crude and rest on processes that are under considerable debate. Table A-8 gives some estimates of electron and ion densities which might exist in Halley that are based on the models for H_2O dominated comets by Mendis and Ip (1976, "The Structure of Cometary Ionospheres I. H_2O Dominated Comets," Icarus 28, 389).

E. SOME RECOMMENDATIONS

We make a number of recommendations for improvement of the model. A more realistic phase function for light scattering from dust should be used. This semi-empirical model should be compared with a purely theoretical model consisting of a dirty ice ball. Worst case models should be developed in addition to the best possible nominal model. An attempt should, perhaps, be made to derive the actual dust to gas ratio in P/Halley from old spectra, attempting calibration of the plates from the apparent strengths of the iron arc comparison lines. It might be possible to derive the actual particle size distribution function for Comet Halley from dust tail photographs, calibrating the plates from star images of known brightness. Improved models should be derived for the inner ionosphere. That used here started with only H_2O and CO and used 21 rate equations. We are informed that W. Huebner is currently working with H_2O, CO_2, NH_3 and over 200 rate equations, for example.

Table A-5. Terminal Velocity with Gravity Included,* m s^{-1}

PARTICLE DIAMETER cm \ HELIOCENTRIC DISTANCE, AU	PRE-PERIHELION			POST-PERIHELION				
	2	1	0.6	0.8	1.0	1.4	2.0	3.0
0.925×10^{-4}	152	390	526	430	398	358	283	160
0.975×10^{-4}	148	387	523	427	395	354	279	156
1.125×10^{-4}	139	379	518	418	383	344	268	147
1.5×10^{-4}	123	345	508	395	358	322	243	130
2.175×10^{-4}	102	315	490	370	328	288	212	109
3.3×10^{-4}	83	286	467	340	294	253	180	88
5.0×10^{-4}	67	252	438	310	260	220	151	72
9.0×10^{-4}	49	212	390	265	218	177	116	53
24.0×10^{-4}	28	151	310	194	157	116	71	30
5.8×10^{-3}	16	112	242	140	119	74	42	18
1.0×10^{-2}	12	78	205	112	84	57	33	13
2.0×10^{-2}	7.5	44	162	80	48	39	22	8.5
5.0×10^{-2}	3.5	33	108	50	35	24	13	4.0
12.0×10^{-2}	1.1	20	69	30	22	14	7.0	1.4
20.0×10^{-2}	0.1	15	52	22	16	9.8	4.8	0.2
5.0×10^{-1}	-	8.3	31	12	8.7	4.9	1.7	-
1.0	-	4.9	21	8.0	5.2	2.7	0.3	-
3.0	-	1.4	10.5	3.1	1.5	0.05	-	-
10.0	-	-	4.4	0.3	-	-	-	-

*These calculations assume a nuclear temperature of 200°K. At 3.0 AU the nucleus will have dropped a bit below 200°K, making the true velocities slightly less than given. At 0.6 AU the temperature may be slightly higher than 200°K and the velocities also higher. Considering the assumptions involved (spherical dust, nuclear albedo, coma opacity, nucleus conductivity, etc.) varying the temperature did not seem warranted.

Table A-6. Dust Concentration at 100 km,* number cm^{-3}

PARTICLE DIAMETER, cm \ HELIOCENTRIC DISTANCE, AU	PRE-PERIHELION			POST-PERIHELION				
	2.0	1.0	0.6	0.8	1.0	1.4	2.0	3.0
0.925×10^{-4}	1.19×10^{-5}	1.30×10^{-4}	8.50×10^{-4}	2.27×10^{-4}	1.36×10^{-4}	7.49×10^{-5}	3.46×10^{-5}	1.25×10^{-5}
0.975×10^{-4}	2.83×10^{-5}	3.02×10^{-4}	1.96×10^{-3}	5.31×10^{-4}	3.16×10^{-4}	1.75×10^{-4}	8.13×10^{-5}	2.95×10^{-5}
1.125×10^{-4}	2.21×10^{-4}	2.25×10^{-3}	1.46×10^{-3}	3.98×10^{-3}	2.39×10^{-3}	1.32×10^{-3}	6.21×10^{-4}	2.30×10^{-4}
1.5×10^{-4}	3.16×10^{-4}	3.14×10^{-3}	1.88×10^{-2}	5.32×10^{-3}	3.25×10^{-3}	1.78×10^{-3}	8.65×10^{-4}	3.29×10^{-4}
2.175×10^{-4}	2.15×10^{-4}	1.94×10^{-3}	1.10×10^{-2}	3.20×10^{-3}	1.99×10^{-3}	1.12×10^{-3}	5.59×10^{-4}	2.21×10^{-4}
3.3×10^{-4}	9.12×10^{-5}	7.37×10^{-4}	3.99×10^{-3}	1.21×10^{-3}	7.69×10^{-4}	4.43×10^{-4}	2.28×10^{-4}	9.22×10^{-5}
5.0×10^{-4}	3.06×10^{-5}	2.27×10^{-4}	1.15×10^{-3}	3.59×10^{-4}	2.36×10^{-4}	1.38×10^{-4}	7.38×10^{-5}	3.14×10^{-5}
9.0×10^{-4}	1.20×10^{-5}	7.69×10^{-5}	3.71×10^{-4}	1.20×10^{-4}	8.03×10^{-5}	4.90×10^{-5}	2.74×10^{-5}	1.22×10^{-5}
24.0×10^{-4}	1.66×10^{-6}	8.59×10^{-6}	3.70×10^{-5}	1.30×10^{-5}	8.87×10^{-6}	5.93×10^{-6}	3.54×10^{-6}	1.71×10^{-6}
5.8×10^{-3}	9.70×10^{-8}	3.85×10^{-7}	1.25×10^{-6}	5.97×10^{-7}	3.89×10^{-7}	3.10×10^{-7}	1.99×10^{-7}	9.46×10^{-8}
1.0×10^{-2}	7.69×10^{-9}	3.29×10^{-8}	1.11×10^{-7}	4.46×10^{-8}	3.29×10^{-8}	2.40×10^{-8}	1.51×10^{-8}	7.84×10^{-9}
2.0×10^{-2}	1.54×10^{-9}	7.31×10^{-9}	1.75×10^{-8}	7.80×10^{-9}	7.18×10^{-9}	4.39×10^{-9}	2.84×10^{-9}	1.49×10^{-9}
5.0×10^{-2}	9.28×10^{-11}	2.75×10^{-10}	7.44×10^{-10}	3.52×10^{-10}	2.77×10^{-10}	2.00×10^{-10}	1.35×10^{-10}	8.93×10^{-11}
12.0×10^{-2}	8.10×10^{-12}	1.24×10^{-11}	3.18×10^{-11}	1.61×10^{-11}	1.21×10^{-11}	9.44×10^{-12}	6.89×10^{-12}	6.99×10^{-12}
20.0×10^{-2}	4.61×10^{-12}	8.59×10^{-13}	2.19×10^{-12}	1.14×10^{-12}	8.60×10^{-13}	6.97×10^{-13}	5.21×10^{-13}	2.54×10^{-12}
5.0×10^{-1}	-	1.33×10^{-13}	3.13×10^{-13}	1.78×10^{-13}	1.36×10^{-13}	1.20×10^{-13}	1.26×10^{-13}	-
1.0	-	6.09×10^{-15}	1.25×10^{-14}	7.24×10^{-15}	6.15×10^{-15}	5.87×10^{-15}	1.93×10^{-14}	-
3.0	-	5.91×10^{-16}	6.94×10^{-16}	5.16×10^{-16}	5.89×10^{-16}	8.75×10^{-15}	-	-
10.0	-	-	1.24×10^{-17}	4.01×10^{-17}	-	-	-	-

*These numbers assume isotropic expansion. They scale to other distances as R^{-2}.

Table A-7. Dust Flux at 100 km,* number $cm^{-2}s^{-1}$

PARTICLE DIAMETER, cm \ HELIOCENTRIC DISTANCE, AU	PRE-PERIHELION			POST-PERIHELION				
	2.0	1.0	0.6	0.8	1.0	1.4	2.0	3.0
0.925×10^{-4}	1.81×10^{-1}	5.05×10^{0}	4.47×10^{1}	9.79×10^{0}	5.42×10^{0}	2.68×10^{0}	9.79×10^{-1}	2.00×10^{-1}
0.975×10^{-4}	4.19×10^{-1}	1.17×10^{1}	1.03×10^{2}	2.27×10^{1}	1.25×10^{1}	6.19×10^{0}	2.27×10^{0}	4.60×10^{-1}
1.125×10^{-4}	3.07×10^{0}	8.51×10^{1}	7.56×10^{2}	1.66×10^{2}	9.15×10^{1}	4.54×10^{1}	1.66×10^{1}	3.37×10^{0}
1.5×10^{-4}	3.88×10^{0}	1.08×10^{2}	9.55×10^{2}	2.10×10^{2}	1.16×10^{2}	5.75×10^{1}	2.10×10^{1}	4.27×10^{0}
2.175×10^{-4}	2.19×10^{0}	6.10×10^{1}	5.40×10^{2}	1.19×10^{2}	8.54×10^{1}	3.24×10^{1}	1.19×10^{1}	2.41×10^{0}
3.3×10^{-4}	7.57×10^{-1}	2.11×10^{1}	1.86×10^{2}	4.10×10^{1}	2.26×10^{1}	1.12×10^{1}	4.10×10^{0}	8.12×10^{-1}
5.0×10^{-4}	2.05×10^{-1}	5.72×10^{0}	5.05×10^{1}	1.11×10^{1}	6.13×10^{0}	3.04×10^{0}	1.11×10^{0}	2.26×10^{-1}
9.0×10^{-4}	5.86×10^{-2}	1.63×10^{0}	1.45×10^{1}	3.18×10^{0}	1.75×10^{0}	8.67×10^{-1}	3.18×10^{-1}	6.45×10^{-2}
24.0×10^{-4}	4.65×10^{-3}	1.30×10^{-1}	1.15×10^{0}	2.51×10^{-1}	1.39×10^{-1}	6.88×10^{-2}	2.51×10^{-2}	5.12×10^{-3}
5.8×10^{-3}	1.55×10^{-4}	4.31×10^{-3}	1.58×10^{-2}	8.36×10^{-3}	4.62×10^{-3}	2.29×10^{-3}	8.36×10^{-4}	1.70×10^{-4}
1.0×10^{-2}	9.23×10^{-6}	2.57×10^{-4}	2.28×10^{-3}	5.00×10^{-4}	2.76×10^{-4}	1.37×10^{-4}	5.00×10^{-5}	1.02×10^{-5}
2.0×10^{-2}	1.15×10^{-6}	3.21×10^{-5}	2.84×10^{-4}	6.24×10^{-5}	3.45×10^{-5}	1.71×10^{-5}	6.25×10^{-5}	1.27×10^{-6}
5.0×10^{-2}	3.25×10^{-8}	9.07×10^{-7}	8.04×10^{-6}	1.76×10^{-6}	9.71×10^{-7}	4.81×10^{-7}	1.76×10^{-7}	3.57×10^{-8}
12.0×10^{-2}	8.91×10^{-10}	2.48×10^{-8}	2.20×10^{-7}	4.82×10^{-8}	2.66×10^{-8}	1.32×10^{-8}	4.82×10^{-9}	9.79×10^{-10}
20.0×10^{-2}	4.62×10^{-11}	1.29×10^{-9}	1.14×10^{-8}	2.50×10^{-9}	1.38×10^{-9}	6.83×10^{-10}	2.50×10^{-10}	5.08×10^{-11}
5.0×10^{-1}	-	1.11×10^{-10}	9.71×10^{-10}	2.14×10^{-10}	1.19×10^{-10}	5.86×10^{-11}	2.14×10^{-11}	-
1.0	-	2.98×10^{-12}	2.63×10^{-11}	5.79×10^{-12}	3.20×10^{-12}	1.58×10^{-12}	5.79×10^{-13}	-
3.0	-	8.28×10^{-14}	7.29×10^{-13}	1.60×10^{-13}	8.83×10^{-14}	4.38×10^{-14}	-	-
10.0	-	-	5.46×10^{-15}	1.20×10^{-15}	-	-	-	-

*These numbers assume isotropic expansion. They scale to other distances as R^{-2}.

Table A-8. Electron and Ion Densities at 1 AU, cm^{-3}

DISTANCE FROM NUCLEUS, km	SPECIES				
	e^-	H_2O^+	H_3O^+	HCO^+	CO^+
50	8×10^5	2×10^5	5×10^5	3×10^4	2×10^4
100	4×10^5	2×10^5	2×10^5	2×10^4	2×10^4
500	8×10^4	4×10^4	5×10^3	7×10^3	1×10^4
1,000	2×10^4	1×10^4	5×10^2	2×10^3	9×10^3
5,000	1×10^3	2×10^2	$<10^{-1}$	2×10^1	8×10^2
10,000	1×10^2	2×10^0	---	2×10^0	1×10^2

This rough model of Halley is unlikely to be in error by more than an order of magnitude in critical areas, and this is probably adequate for the moment. Improvements will be very helpful in detailed experiment and mission design work that must come with an actual project start.

APPENDIX B

THE APPARITION OF COMET HALLEY IN 1986 AS IT IS EXPECTED TO BE SEEN FROM EARTH INCLUDING AN EPHEMERIS

Material primarily contributed by
D.K. Yeomans

APPENDIX B

THE APPARITION OF COMET HALLEY IN 1986 AS IT IS EXPECTED TO BE SEEN FROM EARTH INCLUDING AN EPHEMERIS

The recent experience with Comet Kohoutek is fresh enough to underline the fact that predicting the physical behavior of an active comet is a very risky business. However, in view of the facts (1) that serious efforts to obtain supplementary observations from the Earth or the Space Telescope will be made; (2) that there will be considerable public awareness of Comet Halley's return; and (3) that the apparition will be poorly seen from Earth, particularly at northern latitudes, we provide brief summaries of the viewing opportunities (Fig. B-1 and Table B-1), of the expected total brightness (Table B-1), of tail phenomena (Fig. B-2), and a detailed ephemeris.

The chief points to note are: (1) that the comet passes perihelion near superior conjunction and is therefore not available for terrestrial observations at the height of its activity; (2) in the post-perihelion period when the tail activity is expected to be at its peak and when closest approach to the Earth occurs, the comet is best situated for viewing from southern latitudes.

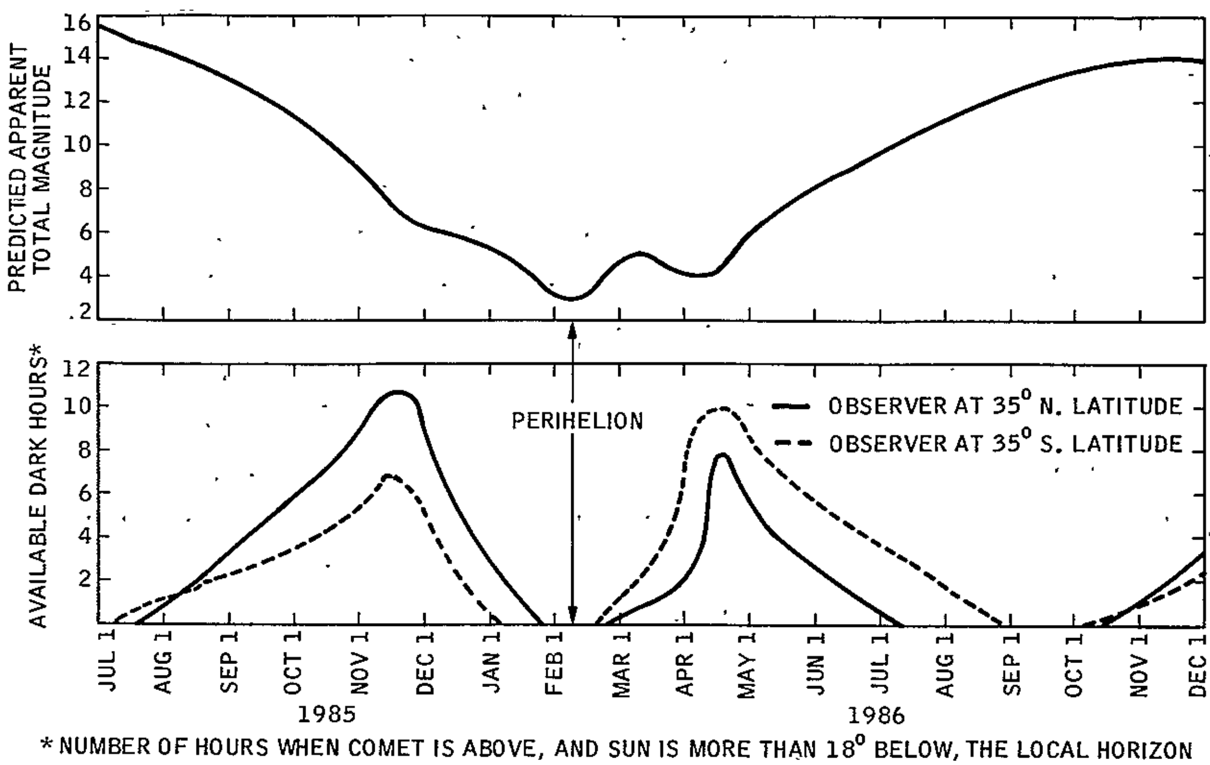

Figure B-1. Comet Halley 1985-86 Ground Based Observing Conditions

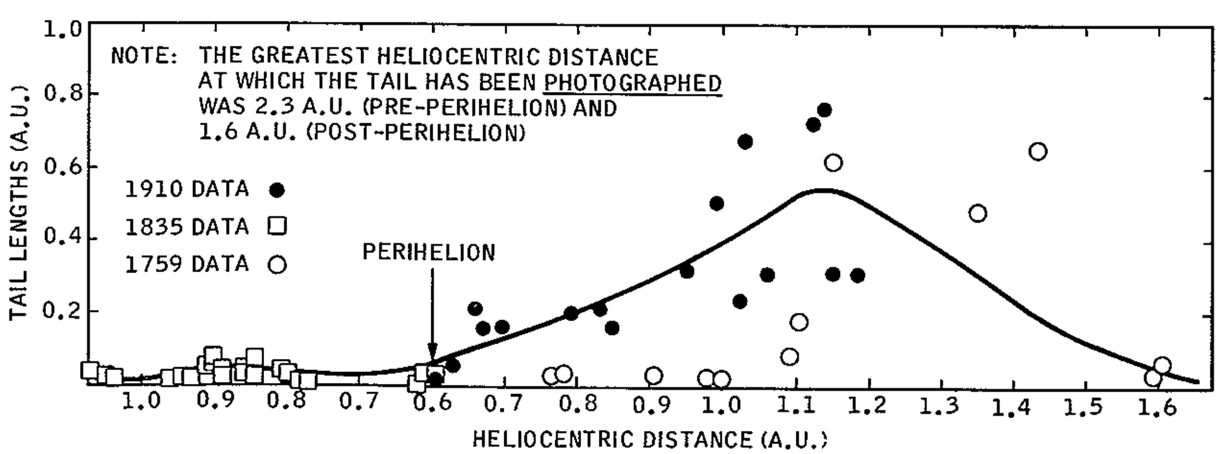

Figure B-2. Comet Halley Tail Lengths Computed from Naked Eye Estimates

Table B-1. Ground-Based Observing Data for Comet Halley 1985-1986

DATE (1985)	DARK HOURS N. LAT. 45°	DARK HOURS N. LAT. 30°	DARK HOURS S. LAT. 30°	DARK HOURS S. LAT. 45°	APPARENT MAGNITUDE* M_1	APPARENT MAGNITUDE* M_2	COMMENTS
Jan. 1	11.6	10.9	6.8	3.5		18.0	Comet is 4.3 AU from Earth and 5.3 AU from Sun
11	10.7	10.0	6.9	3.9		17.8	
21	9.7	9.1	7.2	4.6		17.8	
31	8.7	8.1	5.6	5.3		17.7	
Feb. 10	7.7	7.2	5.0	3.7		17.6	
20	6.8	6.4	4.4	3.3		17.6	
Mar. 2	5.8	5.5	3.9	2.9		17.5	
12	4.9	4.7	3.4	2.5		17.5	
22	4.0	4.0	2.9	2.1		17.4	
Apr. 1	3.2	3.2	2.4	1.8		17.4	
11	2.3	2.5	1.9	1.4		17.3	
21	1.4	1.7	1.5	1.0		17.2	
May 1	0.5	1.0	1.0	0.6		17.1	
11	0	0.3	0.5	0.2		17.0	
21	0	0	0	0		16.9	
31	0	0	0	0		16.7	
June 10	0	0	0	0		16.5	
20	0	0	0	0		16.4	
30	0	0	0	0		16.1	
July 10	0	0	0.3	0.1	14.8	15.9	Comet changes from an evening to a morning object
20	0	0.5	0.8	0.5	14.8	15.7	
30	0.5	1.2	1.3	0.9	14.4	15.4	
Aug. 9	1.4	1.9	1.7	1.3	14.1	15.1	Comet may be visually observable in large telescopes
19	2.3	2.6	2.1	1.6	13.7	14.7	
29	3.2	3.3	2.5	1.9	13.2	14.4	
Sept. 8	4.1	4.0	2.9	2.2	12.7	13.9	
18	5.0	4.8	3.3	2.5	12.2	13.5	
28	5.9	5.6	3.8	2.8	11.6	12.9	

*M_1 is total magnitude, M_2 is nucleus magnitude.

Table B-1. Ground-Based Observing Data for Comet Halley 1985-1986 (contd)

DATE (1985)	DARK HOURS N. LAT. 45°	30°	S. LAT. 30°	45°	APPARENT MAGNITUDE* M_1	M_2	COMMENTS
Oct. 8	6.9	6.4	4.3	3.1	10.9	12.3	
18	8.0	7.3	4.9	3.5	10.2	11.6	
28	9.2	8.5	5.7	4.1	9.3	10.9	Short ion tail may first appear in photographs
Nov. 7	10.7	10.0	6.8	5.0	8.3	10.0	On Nov. 9, Comet passes northward thru ecliptic plane
17	11.1	10.6	7.3	4.9	7.2		Comet near solar opposition
27	10.6	9.8	7.0	4.2	6.4		Comet becoming an evening object
Dec. 7	7.7	7.1	4.4	3.6	6.1		
17	5.5	5.1	2.8	1.0	5.9		Small faint tail (0.5°) may develop
27 (1986)	3.9	3.6	1.5	0	5.6		On Dec 23 comet passes southward thru equatorial plane
Jan. 6	2.6	2.3	0.5	0	5.1		Faint tail may be 1°
16	1.3	1.1	0	0	4.4		
26	0	0	0	0	3.6		
Feb. 5	0	0	0	0	3.0		On Feb. 9, comet passes perihelion
15	0	0	0	0	3.1		
25	0	0.3	0.7	0.5	4.3		Comet changes from an evening to a morning object
Mar. 7	0.2	0.9	2.0	2.0	5.0		On Mar. 10, comet passes southward thru ecliptic plane; faint tail may reach 10°
17	0.5	1.5	3.3	3.7	4.8		Faint tail may reach 20°
27	0.7	2.3	5.3	6.2	4.3		Faint tail could reach 20-40° in length
Apr. 6	0	3.8	9.1	9.4	4.0		On Apr. 11, Comet-earth minimum separation occurs (0.415 AU)
16	6.0	8.3	10.0	9.9	4.4		Comet near solar opposition; faint tail length perhaps 20°
26	6.2	8.0	9.2	10.0	5.5		Comet becoming an evening object; faint tail length perhaps 1°

*M_1 is total magnitude, M_2 is nucleus magnitude.

Table B-1. Ground-Based Observing Data for Comet Halley 1985-1986 (contd)

DATE (1986)	DARK HOURS N. LAT. 45°	DARK HOURS N. LAT. 30°	DARK HOURS S. LAT. 30°	DARK HOURS S. LAT. 45°	APPARENT* MAGNITUDE M_1	APPARENT* MAGNITUDE M2	COMMENTS
May 6	5.5	5.1	7.7	8.3	6.5		
16	2.7	4.3	6.7	7.3	7.3		
26	1.9	3.5	6.0	6.5	7.8	11.5	
June 5	1.0	2.8	5.3	5.8	8.3	12.2	
15	0.2	2.1	4.6	5.1	8.8	12.8	
25	0	1.5	4.0	4.5	9.3	13.3	
July 5	0	0.9	3.4	3.9	9.8	13.8	
15	0	0.4	2.7	3.2	10.3	14.2	
25	0	0	2.1	2.5	10.8	14.6	
Aug. 4	0	0	1.5	1.9	11.4	14.9	
14	0	0	0.9	1.2	11.8	15.2	
24	0	0	0.3	0.5	12.3	15.5	
Sept. 3	0	0	0	0	12.7	15.7	
13	0	0	0	0	13.1	16.0	
23	0	0	0	0	13.4	16.2	
Oct. 3	0	0	0	0	13.6	16.3	
13	0	0.1	0.4	0	13.8	16.5	Comet changes from evening to a morning object
23	0.4	0.8	0.8	0.4	14.0	16.6	
Nov. 2	1.2	1.5	1.2	0.7	14.0	16.8	
12	2.0	2.2	1.7	1.0	14.1	16.9	
22	2.7	2.8	2.3	1.4	14.1	16.9	

Notes: (1) For a particular observer's latitude, the number of dark hours is defined as the time interval during which the sun is below the local horizon by at least 18 degrees and the comet is simultaneously above the local horizon.

(2) Tail length and magnitude estimates are based upon the comet's observed behavior in 1909-11. Predictions are for ideal observing conditions.

Caveat: Predicting the physical behavior of an active comet is risky business. There may be substantial differences between the predicted and observed cometary phenomena.

*M_1 is total magnitude, M_2 is nucleus magnitude.

Table B-2. Comet Halley Ephemeris for 1984-1986

All planetary perturbations and nongravitational forces have been taken into account.

As is the custom, this ephemeris is geocentric and without light time corrections.

Explanation of Symbols

J.D.	Julian date
R.A. and DEC. (1950.0)	Right ascension and declination referred to the mean equator and equinox of 1950.0.
R.A. and DEC. (DATE)	Right ascension and declination referred to the mean equator and equinox of date.
DELTA	Geocentric distance of Comet in AU.
R	Heliocentric distance of Comet in AU.
TMAG	Total magnitude = 5.0 + 5 log (DELTA) + 13.1 log (R) pre-perihelion only. Post-perihelion, TMAG is determined empirically from the 1910-11 magnitude estimates. In cases where TMAG is not computed, the corresponding column is filled with zeroes (0.0).
NMAG	Nuclear magnitude = 7.5 + 5 log (DELTA) + 10 log (R)
THETA	Sun-Earth-Comet angle in degrees.
BETA	Sun-Comet-Earth angle in degrees.
LAT and LONG	Heliocentric ecliptic latitude and longitude in degrees, referred to the equinox of 1950.0.

The following osculating orbital elements are consistent with this emphemeris:

Epoch	2446480.5	1986 Feb. 19.0 E.T.
Perihelion Passage	2446471.16128	1986 Feb. 9.66128 E.T.
Perihelion Distance	0.5870959 AU	
Eccentricity	0.9672671	
Arg. of Perihelion	111.85336	
Long. of Ascending Node	58.15313	
Inclination	162.23779	

Angles are in degrees and are referred to the ecliptic and equinox of 1950.0.

Orbit and ephemeris computations by:

Dr. D.K. Yeomans
Jet Propulsion Laboratory
Pasadena, CA 91103

Table B-2. Comet Halley Ephemeris for 1984-1986 (contd)

YR	MN	DY	HR	J.D.	R.A. 1950.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1984	10	1	.0	2445974.5	6 46.412	+12 52.30	6 48.365	+12 49.92	6.075	6.089	.00	19.26	86.09	9.44	-10.1	91.9
1984	10	3	.0	2445976.5	6 46.325	+12 49.76	6 48.278	+12 47.38	6.023	6.072	.00	19.23	88.04	9.48	-10.1	91.8
1984	10	5	.0	2445978.5	6 46.191	+12 47.22	6 48.143	+12 44.84	5.972	6.055	.00	19.20	90.01	9.51	-10.1	91.8
1984	10	7	.0	2445980.5	6 46.007	+12 44.69	6 47.960	+12 42.32	5.920	6.038	.00	19.17	91.99	9.52	-10.0	91.7
1984	10	9	.0	2445982.5	6 45.774	+12 42.17	6 47.726	+12 39.82	5.868	6.021	.00	19.14	93.99	9.52	-10.0	91.7
1984	10	11	.0	2445984.5	6 45.490	+12 39.68	6 47.441	+12 37.34	5.817	6.004	.00	19.11	96.00	9.52	-10.0	91.6
1984	10	13	.0	2445986.5	6 45.153	+12 37.21	6 47.104	+12 34.89	5.766	5.987	.00	19.08	98.02	9.50	-10.0	91.6
1984	10	15	.0	2445988.5	6 44.762	+12 34.77	6 46.713	+12 32.46	5.714	5.970	.00	19.04	100.06	9.47	-10.0	91.5
1984	10	17	.0	2445990.5	6 44.317	+12 32.35	6 46.268	+12 30.07	5.663	5.953	.00	19.01	102.11	9.42	-10.0	91.4
1984	10	19	.0	2445992.5	6 43.815	+12 29.98	6 45.766	+12 27.72	5.612	5.936	.00	18.98	104.18	9.36	-10.0	91.4
1984	10	21	.0	2445994.5	6 43.256	+12 27.64	6 45.207	+12 25.41	5.562	5.918	.00	18.95	106.26	9.29	-9.9	91.3
1984	10	23	.0	2445996.5	6 42.639	+12 25.35	6 44.590	+12 23.15	5.512	5.901	.00	18.92	108.36	9.21	-9.9	91.3
1984	10	25	.0	2445998.5	6 41.962	+12 23.10	6 43.912	+12 20.94	5.462	5.884	.00	18.88	110.47	9.11	-9.9	91.2
1984	10	27	.0	2446000.5	6 41.225	+12 20.91	6 43.175	+12 18.79	5.413	5.867	.00	18.85	112.60	9.00	-9.9	91.1
1984	10	29	.0	2446002.5	6 40.426	+12 18.79	6 42.377	+12 16.70	5.364	5.849	.00	18.82	114.74	8.87	-9.9	91.1
1984	10	31	.0	2446004.5	6 39.566	+12 16.72	6 41.517	+12 14.67	5.315	5.832	.00	18.79	116.90	8.73	-9.9	91.0
1984	11	2	.0	2446006.5	6 38.644	+12 14.72	6 40.595	+12 12.72	5.268	5.815	.00	18.75	119.07	8.58	-9.8	91.0
1984	11	4	.0	2446008.5	6 37.660	+12 12.79	6 39.610	+12 10.84	5.221	5.797	.00	18.72	121.26	8.41	-9.8	90.9
1984	11	6	.0	2446010.5	6 36.612	+12 10.94	6 38.562	+12 9.04	5.174	5.780	.00	18.69	123.46	8.22	-9.8	90.8
1984	11	8	.0	2446012.5	6 35.501	+12 9.17	6 37.451	+12 7.33	5.129	5.763	.00	18.66	125.67	8.03	-9.8	90.8
1984	11	10	.0	2446014.5	6 34.327	+12 7.49	6 36.277	+12 5.70	5.084	5.745	.00	18.62	127.90	7.82	-9.8	90.7
1984	11	12	.0	2446016.5	6 33.090	+12 5.88	6 35.040	+12 4.16	5.040	5.728	.00	18.59	130.13	7.59	-9.8	90.6
1984	11	14	.0	2446018.5	6 31.789	+12 4.37	6 33.739	+12 2.71	4.996	5.710	.00	18.56	132.38	7.35	-9.7	90.6
1984	11	16	.0	2446020.5	6 30.425	+12 2.95	6 32.376	+12 1.36	4.954	5.693	.00	18.53	134.64	7.10	-9.7	90.5
1984	11	18	.0	2446022.5	6 28.998	+12 1.63	6 30.949	+12 .11	4.913	5.675	.00	18.50	136.91	6.83	-9.7	90.5
1984	11	20	.0	2446024.5	6 27.509	+12 .41	6 29.460	+11 58.97	4.873	5.658	.00	18.47	139.19	6.55	-9.7	90.4
1984	11	22	.0	2446026.5	6 25.959	+11 59.30	6 27.911	+11 57.93	4.834	5.640	.00	18.43	141.47	6.26	-9.7	90.3
1984	11	24	.0	2446028.5	6 24.349	+11 58.29	6 26.301	+11 57.01	4.796	5.622	.00	18.40	143.75	5.96	-9.7	90.3
1984	11	26	.0	2446030.5	6 22.681	+11 57.40	6 24.632	+11 56.20	4.759	5.605	.00	18.37	146.03	5.65	-9.6	90.2
1984	11	28	.0	2446032.5	6 20.955	+11 56.62	6 22.907	+11 55.50	4.723	5.587	.00	18.34	148.31	5.32	-9.6	90.1
1984	11	30	.0	2446034.5	6 19.175	+11 55.95	6 21.127	+11 54.93	4.689	5.569	.00	18.31	150.58	4.99	-9.6	90.1
1984	12	2	.0	2446036.5	6 17.341	+11 55.41	6 19.294	+11 54.48	4.656	5.551	.00	18.28	152.82	4.65	-9.6	90.0
1984	12	4	.0	2446038.5	6 15.457	+11 54.99	6 17.410	+11 54.15	4.624	5.534	.00	18.26	155.04	4.31	-9.6	89.9
1984	12	6	.0	2446040.5	6 13.525	+11 54.68	6 15.478	+11 53.95	4.594	5.516	.00	18.23	157.22	3.97	-9.6	89.9
1984	12	8	.0	2446042.5	6 11.547	+11 54.50	6 13.501	+11 53.87	4.565	5.498	.00	18.20	159.34	3.62	-9.5	89.8
1984	12	10	.0	2446044.5	6 9.527	+11 54.45	6 11.481	+11 53.91	4.538	5.480	.00	18.17	161.37	3.29	-9.5	89.7
1984	12	12	.0	2446046.5	6 7.467	+11 54.52	6 9.421	+11 54.09	4.512	5.462	.00	18.15	163.28	2.97	-9.5	89.7
1984	12	14	.0	2446048.5	6 5.370	+11 54.72	6 7.324	+11 54.39	4.487	5.444	.00	18.12	165.02	2.68	-9.5	89.6
1984	12	16	.0	2446050.5	6 3.240	+11 55.04	6 5.195	+11 54.82	4.464	5.426	.00	18.09	166.50	2.43	-9.5	89.5
1984	12	18	.0	2446052.5	6 1.080	+11 55.49	6 3.035	+11 55.39	4.443	5.408	.00	18.07	167.65	2.23	-9.4	89.4
1984	12	20	.0	2446054.5	5 58.894	+11 56.07	6 .850	+11 56.08	4.423	5.390	.00	18.04	168.34	2.11	-9.4	89.4
1984	12	22	.0	2446056.5	5 56.687	+11 56.79	5 58.644	+11 56.91	4.405	5.372	.00	18.02	168.49	2.09	-9.4	89.3
1984	12	24	.0	2446058.5	5 54.463	+11 57.63	5 56.420	+11 57.86	4.388	5.354	.00	18.00	168.08	2.18	-9.4	89.2
1984	12	26	.0	2446060.5	5 52.226	+11 58.61	5 54.183	+11 58.96	4.372	5.336	.00	17.98	167.15	2.35	-9.4	89.2
1984	12	28	.0	2446062.5	5 49.980	+11 59.72	5 51.938	+12 .18	4.359	5.318	.00	17.95	165.82	2.60	-9.3	89.1
1984	12	30	.0	2446064.5	5 47.731	+12 .96	5 49.689	+12 1.53	4.347	5.299	.00	17.93	164.17	2.90	-9.3	89.0
1985	1	1	.0	2446066.5	5 45.481	+12 2.32	5 47.440	+12 3.01	4.336	5.281	.00	17.91	162.31	3.24	-9.3	88.9
1985	1	3	.0	2446068.5	5 43.237	+12 3.82	5 45.197	+12 4.63	4.327	5.263	.00	17.89	160.28	3.61	-9.3	88.9
1985	1	5	.0	2446070.5	5 41.002	+12 5.45	5 42.962	+12 6.37	4.319	5.245	.00	17.87	158.14	4.00	-9.3	88.8
1985	1	7	.0	2446072.5	5 38.780	+12 7.20	5 40.741	+12 8.23	4.313	5.226	.00	17.86	155.92	4.40	-9.2	88.7
1985	1	9	.0	2446074.5	5 36.576	+12 9.08	5 38.537	+12 10.22	4.308	5.208	.00	17.84	153.65	4.81	-9.2	88.6
1985	1	11	.0	2446076.5	5 34.393	+12 11.09	5 36.355	+12 12.34	4.305	5.189	.00	17.82	151.33	5.22	-9.2	88.6
1985	1	13	.0	2446078.5	5 32.236	+12 13.21	5 34.199	+12 14.58	4.303	5.171	.00	17.80	148.97	5.63	-9.2	88.5
1985	1	15	.0	2446080.5	5 30.108	+12 15.47	5 32.072	+12 16.94	4.303	5.153	.00	17.79	146.60	6.03	-9.2	88.4

Table B-2. Comet Halley Ephemeris for 1984-1986 (contd)

YR	MN	DY	HR	J.D.	R.A. 1950.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1985	1	17	.0	2446082.5	5 28.014	+12 17.85	5 29.978	+12 19.42	4.304	5.134	.00	17.77	144.21	6.43	-9.1	88.3
1985	1	19	.0	2446084.5	5 25.958	+12 20.35	5 27.922	+12 22.03	4.306	5.115	.00	17.76	141.81	6.83	-9.1	88.2
1985	1	21	.0	2446086.5	5 23.942	+12 22.97	5 25.907	+12 24.75	4.309	5.097	.00	17.75	139.41	7.22	-9.1	88.2
1985	1	23	.0	2446088.5	5 21.971	+12 25.71	5 23.937	+12 27.60	4.314	5.078	.00	17.73	137.01	7.60	-9.1	88.1
1985	1	25	.0	2446090.5	5 20.047	+12 28.57	5 22.014	+12 30.55	4.320	5.060	.00	17.72	134.60	7.96	-9.1	88.0
1985	1	27	.0	2446092.5	5 18.174	+12 31.55	5 20.141	+12 33.63	4.326	5.041	.00	17.71	132.20	8.32	-9.0	87.9
1985	1	29	.0	2446094.5	5 16.354	+12 34.64	5 18.322	+12 36.81	4.334	5.022	.00	17.69	129.81	8.66	-9.0	87.8
1985	1	31	.0	2446096.5	5 14.589	+12 37.85	5 16.558	+12 40.10	4.343	5.003	.00	17.68	127.43	9.00	-9.0	87.8
1985	2	2	.0	2446098.5	5 12.882	+12 41.16	5 14.852	+12 43.50	4.353	4.985	.00	17.67	125.06	9.31	-9.0	87.7
1985	2	4	.0	2446100.5	5 11.234	+12 44.58	5 13.205	+12 47.01	4.364	4.966	.00	17.66	122.69	9.62	-8.9	87.6
1985	2	6	.0	2446102.5	5 9.648	+12 48.10	5 11.619	+12 50.61	4.375	4.947	.00	17.65	120.34	9.91	-8.9	87.5
1985	2	6	.0	2446104.5	5 8.123	+12 51.73	5 10.096	+12 54.31	4.387	4.928	.00	17.64	118.00	10.18	-8.9	87.4
1985	2	10	.0	2446106.5	5 6.662	+12 55.45	5 8.636	+12 58.11	4.400	4.909	.00	17.63	115.68	10.44	-8.9	87.3
1985	2	12	.0	2446108.5	5 5.266	+12 59.28	5 7.241	+13 2.00	4.414	4.890	.00	17.62	113.37	10.68	-8.9	87.3
1985	2	14	.0	2446110.5	5 3.936	+13 3.20	5 5.911	+13 5.99	4.428	4.871	.00	17.61	111.07	10.91	-8.8	87.2
1985	2	16	.0	2446112.5	5 2.672	+13 7.21	5 4.648	+13 10.06	4.443	4.852	.00	17.60	108.79	11.11	-8.8	87.1
1985	2	18	.0	2446114.5	5 1.475	+13 11.31	5 3.453	+13 14.23	4.458	4.833	.00	17.59	106.52	11.31	-8.8	87.0
1985	2	20	.0	2446116.5	5 .347	+13 15.50	5 2.325	+13 18.47	4.474	4.814	.00	17.58	104.28	11.48	-8.8	86.9
1985	2	22	.0	2446118.5	4 59.286	+13 19.77	5 1.266	+13 22.80	4.490	4.795	.00	17.57	102.04	11.64	-8.7	86.8
1985	2	24	.0	2446120.5	4 58.293	+13 24.13	5 .274	+13 27.20	4.506	4.775	.00	17.56	99.83	11.78	-8.7	86.7
1985	2	26	.0	2446122.5	4 57.368	+13 28.56	4 59.350	+13 31.68	4.522	4.756	.00	17.55	97.63	11.91	-8.7	86.6
1985	2	28	.0	2446124.5	4 56.510	+13 33.06	4 58.493	+13 36.22	4.539	4.737	.00	17.54	95.45	12.02	-8.7	86.5
1985	3	2	.0	2446126.5	4 55.719	+13 37.63	4 57.704	+13 40.83	4.556	4.718	.00	17.53	93.28	12.11	-8.6	86.4
1985	3	4	.0	2446128.5	4 54.995	+13 42.26	4 56.981	+13 45.50	4.573	4.698	.00	17.52	91.14	12.18	-8.6	86.4
1985	3	6	.0	2446130.5	4 54.336	+13 46.96	4 56.323	+13 50.23	4.590	4.679	.00	17.51	89.01	12.24	-8.6	86.3
1985	3	8	.0	2446132.5	4 53.741	+13 51.71	4 55.730	+13 55.02	4.606	4.659	.00	17.50	86.90	12.28	-8.6	86.2
1985	3	10	.0	2446134.5	4 53.211	+13 56.52	4 55.200	+13 59.85	4.623	4.640	.00	17.49	84.80	12.31	-8.5	86.1
1985	3	12	.0	2446136.5	4 52.744	+14 1.38	4 54.734	+14 4.73	4.640	4.620	.00	17.48	82.72	12.32	-8.5	86.0
1985	3	14	.0	2446138.5	4 52.339	+14 6.28	4 54.331	+14 9.66	4.656	4.601	.00	17.47	80.66	12.31	-8.5	85.9
1985	3	16	.0	2446140.5	4 51.995	+14 11.24	4 53.989	+14 14.62	4.673	4.581	.00	17.46	78.61	12.29	-8.4	85.8
1985	3	18	.0	2446142.5	4 51.712	+14 16.23	4 53.707	+14 19.63	4.689	4.561	.00	17.45	76.58	12.25	-8.4	85.7
1985	3	20	.0	2446144.5	4 51.489	+14 21.25	4 53.485	+14 24.67	4.704	4.542	.00	17.43	74.57	12.20	-8.4	85.6
1985	3	22	.0	2446146.5	4 51.324	+14 26.32	4 53.322	+14 29.74	4.719	4.522	.00	17.42	72.57	12.14	-8.4	85.5
1985	3	24	.0	2446148.5	4 51.217	+14 31.41	4 53.216	+14 34.84	4.734	4.502	.00	17.41	70.58	12.06	-8.3	85.4
1985	3	26	.0	2446150.5	4 51.165	+14 36.52	4 53.166	+14 39.95	4.749	4.482	.00	17.40	68.62	11.96	-8.3	85.3
1985	3	28	.0	2446152.5	4 51.169	+14 41.66	4 53.171	+14 45.09	4.763	4.462	.00	17.39	66.66	11.85	-8.3	85.2
1985	3	30	.0	2446154.5	4 51.225	+14 46.81	4 53.229	+14 50.24	4.776	4.443	.00	17.37	64.73	11.73	-8.3	85.1
1985	4	1	.0	2446156.5	4 51.334	+14 51.97	4 53.339	+14 55.40	4.789	4.423	.00	17.36	62.80	11.59	-8.2	85.0
1985	4	3	.0	2446158.5	4 51.493	+14 57.15	4 53.500	+15 .56	4.801	4.403	.00	17.34	60.90	11.45	-8.2	84.9
1985	4	5	.0	2446160.5	4 51.702	+15 2.33	4 53.711	+15 5.73	4.813	4.383	.00	17.33	59.00	11.28	-8.2	84.7
1985	4	7	.0	2446162.5	4 51.959	+15 7.51	4 53.969	+15 10.90	4.824	4.362	.00	17.31	57.12	11.11	-8.1	84.6
1985	4	9	.0	2446164.5	4 52.263	+15 12.69	4 54.274	+15 16.07	4.834	4.342	.00	17.30	55.26	10.93	-8.1	84.5
1985	4	11	.0	2446166.5	4 52.612	+15 17.87	4 54.626	+15 21.23	4.844	4.322	.00	17.28	53.41	10.73	-8.1	84.4
1985	4	13	.0	2446168.5	4 53.007	+15 23.04	4 55.022	+15 26.38	4.853	4.302	.00	17.27	51.57	10.52	-8.0	84.3
1985	4	15	.0	2446170.5	4 53.445	+15 28.20	4 55.462	+15 31.53	4.861	4.282	.00	17.25	49.74	10.30	-8.0	84.2
1985	4	17	.0	2446172.5	4 53.926	+15 33.35	4 55.944	+15 36.65	4.868	4.261	.00	17.23	47.92	10.07	-8.0	84.1
1985	4	19	.0	2446174.5	4 54.448	+15 38.49	4 56.468	+15 41.76	4.875	4.241	.00	17.21	46.12	9.83	-7.9	84.0
1985	4	21	.0	2446176.5	4 55.010	+15 43.60	4 57.032	+15 46.85	4.881	4.220	.00	17.20	44.33	9.58	-7.9	83.9
1985	4	23	.0	2446178.5	4 55.611	+15 48.69	4 57.634	+15 51.91	4.885	4.200	.00	17.18	42.55	9.32	-7.9	83.7
1985	4	25	.0	2446180.5	4 56.250	+15 53.76	4 58.275	+15 56.95	4.889	4.179	.00	17.16	40.78	9.05	-7.8	83.6
1985	4	27	.0	2446182.5	4 56.924	+15 58.80	4 58.951	+16 1.95	4.892	4.159	.00	17.14	39.03	8.77	-7.8	83.5
1985	4	29	.0	2446184.5	4 57.634	+16 3.80	4 59.663	+16 6.92	4.894	4.138	.00	17.12	37.29	8.48	-7.8	83.4
1985	5	1	.0	2446186.5	4 58.378	+16 8.77	5 .408	+16 11.85	4.895	4.118	.00	17.10	35.56	8.18	-7.7	83.3
1985	5	3	.0	2446188.5	4 59.154	+16 13.70	5 1.186	+16 16.75	4.896	4.097	.00	17.07	33.84	7.87	-7.7	83.1
1985	5	5	.0	2446190.5	4 59.962	+16 18.59	5 1.995	+16 21.60	4.895	4.076	.00	17.05	32.13	7.56	-7.7	83.0
1985	5	7	.0	2446192.5	5 .800	+16 23.45	5 2.835	+16 26.41	4.893	4.055	.00	17.03	30.43	7.24	-7.6	82.9
1985	5	9	.0	2446194.5	5 1.668	+16 28.25	5 3.705	+16 31.18	4.890	4.034	.00	17.00	28.74	6.91	-7.6	82.8

Table B-2. Comet Halley Ephemeris for 1984-1986 (contd)

YR	MN	DY	HR	J.D.	R.A. 1950.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1985	5	11	.0	2446196.5	5 2.565	+16 33.02	5 4.603	+16 35.89	4.886	4.013	.00	16.98	27.07	6.58	-7.6	82.6
1985	5	13	.0	2446198.5	5 3.489	+16 37.73	5 5.529	+16 40.56	4.882	3.992	.00	16.96	25.41	6.23	-7.5	82.5
1985	5	15	.0	2446200.5	5 4.441	+16 42.40	5 6.483	+16 45.18	4.876	3.971	.00	16.93	23.76	5.89	-7.5	82.4
1985	5	17	.0	2446202.5	5 5.418	+16 47.01	5 7.462	+16 49.75	4.869	3.950	.00	16.90	22.12	5.53	-7.5	82.3
1985	5	19	.0	2446204.5	5 6.420	+16 51.57	5 8.465	+16 54.26	4.861	3.929	.00	16.88	20.50	5.17	-7.4	82.1
1985	5	21	.0	2446206.5	5 7.446	+16 56.07	5 9.493	+16 58.71	4.852	3.908	.00	16.85	18.89	4.81	-7.4	82.0
1985	5	23	.0	2446208.5	5 8.495	+17 .52	5 10.543	+17 3.10	4.842	3.887	.00	16.82	17.30	4.44	-7.3	81.9
1985	5	25	.0	2446210.5	5 9.565	+17 4.90	5 11.615	+17 7.43	4.831	3.865	.00	16.79	15.74	4.08	-7.3	81.7
1985	5	27	.0	2446212.5	5 10.655	+17 9.22	5 12.707	+17 11.70	4.918	3.844	.00	16.76	14.20	3.71	-7.3	81.6
1985	5	29	.0	2446214.5	5 11.765	+17 13.48	5 13.819	+17 15.90	4.805	3.823	.00	16.73	12.69	3.34	-7.2	81.4
1985	5	31	.0	2446216.5	5 12.894	+17 17.67	5 14.949	+17 20.03	4.791	3.801	.00	16.70	11.23	2.98	-7.2	81.3
1985	6	2	.0	2446218.5	5 14.040	+17 21.80	5 16.097	+17 24.10	4.775	3.780	.00	16.67	9.83	2.63	-7.1	81.2
1985	6	4	.0	2446220.5	5 15.204	+17 25.86	5 17.262	+17 28.10	4.758	3.758	.00	16.64	8.52	2.29	-7.1	81.0
1985	6	6	.0	2446222.5	5 16.383	+17 29.85	5 18.442	+17 32.03	4.741	3.736	.00	16.60	7.33	1.99	-7.1	80.9
1985	6	8	.0	2446224.5	5 17.577	+17 33.77	5 19.639	+17 35.90	4.722	3.715	.00	16.57	6.36	1.73	-7.0	80.7
1985	6	10	.0	2446226.5	5 18.787	+17 37.63	5 20.849	+17 39.69	4.702	3.693	.00	16.54	5.68	1.56	-7.0	80.6
1985	6	12	.0	2446228.5	5 20.010	+17 41.41	5 22.074	+17 43.41	4.681	3.671	.00	16.50	5.42	1.50	-6.9	80.4
1985	6	14	.0	2446230.5	5 21.245	+17 45.12	5 23.311	+17 47.06	4.659	3.649	.00	16.46	5.63	1.56	-6.9	80.3
1985	6	16	.0	2446232.5	5 22.493	+17 48.76	5 24.560	+17 50.64	4.636	3.627	.00	16.43	6.26	1.75	-6.8	80.1
1985	6	18	.0	2446234.5	5 23.752	+17 52.33	5 25.820	+17 54.14	4.611	3.605	.00	16.39	7.20	2.02	-6.8	80.0
1985	6	20	.0	2446236.5	5 25.020	+17 55.82	5 27.090	+17 57.57	4.586	3.583	.00	16.35	8.34	2.36	-6.7	79.8
1985	6	22	.0	2446238.5	5 26.297	+17 59.24	5 28.368	+18 .92	4.559	3.561	.00	16.31	9.61	2.73	-6.7	79.6
1985	6	24	.0	2446240.5	5 27.582	+18 2.58	5 29.655	+18 4.20	4.532	3.539	.00	16.27	10.97	3.13	-6.6	79.5
1985	6	26	.0	2446242.5	5 28.874	+18 5.85	5 30.948	+18 7.40	4.503	3.517	.00	16.23	12.38	3.55	-6.6	79.3
1985	6	28	.0	2446244.5	5 30.171	+18 9.04	5 32.247	+18 10.53	4.473	3.494	.00	16.19	13.84	3.99	-6.5	79.1
1985	6	30	.0	2446246.5	5 31.474	+18 12.16	5 33.550	+18 13.58	4.442	3.472	.00	16.14	15.31	4.44	-6.5	79.0
1985	7	2	.0	2446248.5	5 32.781	+18 15.20	5 34.859	+18 16.56	4.410	3.450	.00	16.10	16.81	4.89	-6.4	78.8
1985	7	4	.0	2446250.5	5 34.091	+18 18.18	5 36.170	+18 19.46	4.377	3.427	.00	16.06	18.33	5.35	-6.4	78.6
1985	7	6	.0	2446252.5	5 35.404	+18 21.08	5 37.484	+18 22.29	4.343	3.405	.00	16.01	19.85	5.82	-6.3	78.5
1985	7	8	.0	2446254.5	5 36.719	+18 23.90	5 38.800	+18 25.05	4.308	3.382	.00	15.96	21.39	6.29	-6.3	78.3
1985	7	10	.0	2446256.5	5 38.034	+18 26.66	5 40.117	+18 27.74	4.272	3.359	.00	15.92	22.93	6.77	-6.2	78.1
1985	7	12	.0	2446258.5	5 39.349	+18 29.35	5 41.433	+18 30.36	4.235	3.336	14.99	15.87	24.48	7.25	-6.2	77.9
1985	7	14	.0	2446260.5	5 40.663	+18 31.96	5 42.748	+18 32.91	4.197	3.314	14.93	15.82	26.04	7.74	-6.1	77.7
1985	7	16	.0	2446262.5	5 41.975	+18 34.51	5 44.060	+18 35.39	4.158	3.291	14.87	15.77	27.60	8.23	-6.1	77.5
1985	7	18	.0	2446264.5	5 43.282	+18 36.99	5 45.369	+18 37.80	4.117	3.268	14.81	15.72	29.17	8.72	-6.0	77.4
1985	7	20	.0	2446266.5	5 44.585	+18 39.40	5 46.673	+18 40.14	4.076	3.245	14.75	15.66	30.74	9.21	-6.0	77.2
1985	7	22	.0	2446268.5	5 45.881	+18 41.74	5 47.970	+18 42.42	4.034	3.221	14.68	15.61	32.31	9.71	-5.9	77.0
1985	7	24	.0	2446270.5	5 47.169	+18 44.03	5 49.259	+18 44.64	3.991	3.198	14.62	15.55	33.89	10.20	-5.8	76.8
1985	7	26	.0	2446272.5	5 48.449	+18 46.25	5 50.540	+18 46.79	3.947	3.175	14.55	15.50	35.48	10.70	-5.8	76.6
1985	7	28	.0	2446274.5	5 49.718	+18 48.41	5 51.810	+18 48.89	3.902	3.152	14.49	15.44	37.07	11.20	-5.7	76.4
1985	7	30	.0	2446276.5	5 50.977	+18 50.52	5 53.069	+18 50.94	3.856	3.128	14.42	15.38	38.67	11.70	-5.7	76.2
1985	8	1	.0	2446278.5	5 52.222	+18 52.58	5 54.316	+18 52.93	3.809	3.105	14.35	15.32	40.27	12.20	-5.6	76.0
1985	8	3	.0	2446280.5	5 53.454	+18 54.59	5 55.549	+18 54.88	3.761	3.081	14.28	15.26	41.87	12.70	-5.5	75.7
1985	8	5	.0	2446282.5	5 54.671	+18 56.56	5 56.766	+18 56.78	3.713	3.057	14.21	15.20	43.48	13.20	-5.5	75.5
1985	8	7	.0	2446284.5	5 55.871	+18 58.48	5 57.967	+18 58.64	3.663	3.034	14.13	15.14	45.10	13.70	-5.4	75.3
1985	8	9	.0	2446286.5	5 57.052	+19 .36	5 59.149	+19 .46	3.613	3.010	14.06	15.07	46.73	14.20	-5.3	75.1
1985	8	11	.0	2446288.5	5 58.214	+19 2.20	6 .311	+19 2.24	3.562	2.986	13.98	15.01	48.36	14.69	-5.3	74.9
1985	8	13	.0	2446290.5	5 59.352	+19 4.02	6 1.451	+19 4.00	3.510	2.962	13.90	14.94	50.00	15.19	-5.2	74.6
1985	8	15	.0	2446292.5	6 .467	+19 5.81	6 2.566	+19 5.73	3.457	2.938	13.82	14.87	51.65	15.69	-5.1	74.4
1985	8	17	.0	2446294.5	6 1.554	+19 7.57	6 3.654	+19 7.44	3.403	2.914	13.74	14.80	53.30	16.18	-5.0	74.2
1985	8	19	.0	2446296.5	6 2.613	+19 9.32	6 4.713	+19 9.13	3.349	2.889	13.66	14.73	54.97	16.67	-5.0	73.9
1985	8	21	.0	2446298.5	6 3.639	+19 11.06	6 5.741	+19 10.82	3.294	2.865	13.58	14.66	56.64	17.15	-4.9	73.7
1985	8	23	.0	2446300.5	6 4.632	+19 12.79	6 6.734	+19 12.50	3.238	2.841	13.49	14.59	58.33	17.64	-4.8	73.4
1985	8	25	.0	2446302.5	6 5.588	+19 14.53	6 7.691	+19 14.19	3.182	2.816	13.40	14.51	60.02	18.11	-4.7	73.2
1985	8	27	.0	2446304.5	6 6.505	+19 16.29	6 8.609	+19 15.89	3.125	2.792	13.31	14.43	61.73	18.59	-4.7	72.9
1985	8	29	.0	2446306.5	6 7.380	+19 18.06	6 9.484	+19 17.62	3.067	2.767	13.22	14.35	63.44	19.05	-4.6	72.6
1985	8	31	.0	2446308.5	6 8.209	+19 19.86	6 10.314	+19 19.37	3.008	2.742	13.13	14.27	65.17	19.52	-4.5	72.4

Table B-2. Comet Halley Ephemeris for 1984-1986 (contd)

YR	MN	DY	HR	J.D.	R.A. 1950.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1985	9	2	.0	2446310.5	6 8.990	+19 21.69	6 11.096	+19 21.17	2.949	2.717	13.04	14.19	66.92	19.97	-4.4	72.1
1985	9	4	.0	2446312.5	6 9.718	+19 23.57	6 11.825	+19 23.01	2.890	2.692	12.94	14.11	68.68	20.42	-4.3	71.8
1985	9	6	.0	2446314.5	6 10.390	+19 25.51	6 12.497	+19 24.92	2.830	2.667	12.84	14.02	70.45	20.86	-4.2	71.5
1985	9	8	.0	2446316.5	6 11.000	+19 27.51	6 13.108	+19 26.89	2.769	2.642	12.74	13.93	72.24	21.29	-4.2	71.3
1985	9	10	.0	2446318.5	6 11.544	+19 29.60	6 13.653	+19 28.94	2.708	2.617	12.64	13.84	74.05	21.71	-4.1	71.0
1985	9	12	.0	2446320.5	6 12.016	+19 31.77	6 14.126	+19 31.09	2.646	2.592	12.53	13.75	75.88	22.12	-4.0	70.7
1985	9	14	.0	2446322.5	6 12.410	+19 34.05	6 14.521	+19 33.35	2.584	2.566	12.42	13.65	77.73	22.52	-3.9	70.4
1985	9	16	.0	2446324.5	6 12.720	+19 36.44	6 14.832	+19 35.73	2.522	2.541	12.31	13.56	79.60	22.91	-3.8	70.0
1985	9	18	.0	2446326.5	6 12.938	+19 38.97	6 15.050	+19 38.25	2.459	2.515	12.20	13.46	81.50	23.27	-3.7	69.7
1985	9	20	.0	2446328.5	6 13.056	+19 41.66	6 15.170	+19 40.92	2.396	2.489	12.09	13.36	83.42	23.63	-3.6	69.4
1985	9	22	.0	2446330.5	6 13.067	+19 44.51	6 15.182	+19 43.78	2.332	2.463	11.97	13.25	85.37	23.96	-3.5	69.1
1985	9	24	.0	2446332.5	6 12.962	+19 47.56	6 15.078	+19 46.83	2.268	2.438	11.85	13.15	87.35	24.27	-3.4	68.7
1985	9	26	.0	2446334.5	6 12.730	+19 50.82	6 14.847	+19 50.10	2.204	2.412	11.72	13.04	89.36	24.56	-3.3	68.4
1985	9	28	.0	2446336.5	6 12.360	+19 54.30	6 14.478	+19 53.61	2.140	2.385	11.60	12.93	91.41	24.83	-3.1	68.0
1985	9	30	.0	2446338.5	6 11.839	+19 58.05	6 13.959	+19 57.37	2.076	2.359	11.47	12.81	93.49	25.07	-3.0	67.7
1985	10	2	.0	2446340.5	6 11.154	+20 2.07	6 13.275	+20 1.43	2.011	2.333	11.34	12.70	95.62	25.28	-2.9	67.3
1985	10	4	.0	2446342.5	6 10.287	+20 6.38	6 12.410	+20 5.79	1.947	2.306	11.20	12.58	97.79	25.45	-2.8	66.9
1985	10	6	.0	2446344.5	6 9.221	+20 11.03	6 11.345	+20 10.49	1.882	2.280	11.06	12.45	100.01	25.59	-2.7	66.6
1985	10	8	.0	2446346.5	6 7.934	+20 16.02	6 10.060	+20 15.55	1.818	2.253	10.92	12.33	102.28	25.68	-2.6	66.2
1985	10	10	.0	2446348.5	6 6.404	+20 21.39	6 8.532	+20 21.00	1.754	2.226	10.77	12.20	104.61	25.72	-2.4	65.8
1985	10	12	.0	2446350.5	6 4.603	+20 27.16	6 6.733	+20 26.86	1.689	2.199	10.62	12.06	107.01	25.72	-2.3	65.3
1985	10	14	.0	2446352.5	6 2.502	+20 33.35	6 4.634	+20 33.16	1.625	2.172	10.47	11.92	109.49	25.65	-2.2	64.9
1985	10	16	.0	2446354.5	6 .066	+20 39.98	6 2.200	+20 39.92	1.562	2.145	10.31	11.78	112.04	25.52	-2.0	64.5
1985	10	18	.0	2446356.5	5 57.257	+20 47.06	5 59.393	+20 47.15	1.499	2.118	10.15	11.64	114.68	25.31	-1.9	64.0
1985	10	20	.0	2446358.5	5 54.030	+20 54.60	5 56.168	+20 54.85	1.436	2.090	9.98	11.49	117.42	25.01	-1.7	63.6
1985	10	22	.0	2446360.5	5 50.335	+21 2.58	5 52.476	+21 3.02	1.374	2.063	9.81	11.33	120.27	24.62	-1.6	63.1
1985	10	24	.0	2446362.5	5 46.114	+21 10.97	5 48.257	+21 11.64	1.312	2.035	9.63	11.18	123.24	24.12	-1.4	62.6
1985	10	26	.0	2446364.5	5 41.300	+21 19.71	5 43.445	+21 20.63	1.252	2.008	9.45	11.01	126.36	23.50	-1.3	62.1
1985	10	28	.0	2446366.5	5 35.816	+21 28.71	5 37.964	+21 29.91	1.192	1.980	9.27	10.85	129.62	22.74	-1.1	61.6
1985	10	30	.0	2446368.5	5 29.575	+21 37.80	5 31.724	+21 39.33	1.134	1.952	9.08	10.68	133.07	21.82	-.9	61.1
1985	11	1	.0	2446370.5	5 22.476	+21 46.75	5 24.626	+21 48.65	1.077	1.924	8.88	10.50	136.71	20.72	-.8	60.6
1985	11	3	.0	2446372.5	5 14.407	+21 55.23	5 16.558	+21 57.54	1.021	1.895	8.68	10.32	140.57	19.42	-.6	60.0
1985	11	5	.0	2446374.5	5 5.244	+22 2.76	5 7.395	+22 5.54	.968	1.867	8.48	10.14	144.69	17.88	-.4	59.5
1985	11	7	.0	2446376.5	4 54.853	+22 8.69	4 57.002	+22 11.99	.916	1.838	8.27	9.95	149.08	16.08	-.2	58.9
1985	11	9	.0	2446378.5	4 43.096	+22 12.14	4 45.241	+22 16.03	.867	1.810	8.07	9.77	153.79	13.99	-.0	58.3
1985	11	11	.0	2446380.5	4 29.839	+22 11.96	4 31.979	+22 16.50	.821	1.791	7.86	9.58	158.83	11.58	.2	57.6
1985	11	13	.0	2446382.5	4 14.970	+22 6.73	4 17.099	+22 11.98	.779	1.752	7.65	9.39	164.24	8.83	.4	57.0
1985	11	15	.0	2446384.5	3 58.413	+21 54.70	4 .529	+22 .71	.740	1.723	7.44	9.21	169.98	5.73	.6	56.3
1985	11	17	.0	2446386.5	3 40.162	+21 33.96	3 42.261	+21 40.78	.706	1.694	7.24	9.03	175.83	2.43	.8	55.6
1985	11	19	.0	2446388.5	3 20.308	+21 2.58	3 22.383	+21 10.23	.677	1.664	7.05	8.87	176.10	2.32	1.0	54.9
1985	11	21	.0	2446390.5	2 59.059	+20 18.92	3 1.107	+20 27.39	.654	1.635	6.87	8.71	169.55	6.29	1.3	54.2
1985	11	23	.0	2446392.5	2 36.756	+19 22.03	2 38.774	+19 31.29	.636	1.605	6.71	8.57	162.32	10.77	1.5	53.4
1985	11	25	.0	2446394.5	2 13.856	+18 12.06	2 15.841	+18 22.04	.626	1.576	6.57	8.46	154.81	15.46	1.8	52.6
1985	11	27	.0	2446396.5	1 50.882	+16 50.43	1 52.836	+17 1.02	.621	1.546	6.44	8.36	147.18	20.24	2.0	51.8
1985	11	29	.0	2446398.5	1 28.367	+15 19.73	1 30.290	+15 30.83	.624	1.516	6.34	8.28	139.57	24.96	2.3	50.9
1985	12	1	.0	2446400.5	1 6.776	+13 43.37	1 8.673	+13 54.85	.632	1.486	6.26	8.22	132.10	29.50	2.6	50.0
1985	12	3	.0	2446402.5	0 46.467	+12 4.95	0 48.343	+12 16.69	.647	1.456	6.19	8.18	124.88	33.75	2.9	49.1
1985	12	5	.0	2446404.5	0 27.667	+10 27.72	0 29.526	+10 39.62	.667	1.425	6.14	8.16	117.98	37.63	3.2	48.1
1985	12	7	.0	2446406.5	0 10.479	+ 8 54.25	0 12.326	+ 9 6.23	.691	1.395	6.09	8.14	111.46	41.09	3.5	47.1
1985	12	9	.0	2446408.5	23 54.906	+ 7 26.29	23 56.745	+ 7 38.29	.719	1.364	6.05	8.13	105.32	44.12	3.9	46.0
1985	12	11	.0	2446410.5	23 40.880	+ 6 4.83	23 42.715	+ 6 16.79	.751	1.334	6.02	8.13	99.57	46.72	4.2	44.9
1985	12	13	.0	2446412.5	23 28.291	+ 4 50.23	23 30.123	+ 5 2.13	.785	1.303	5.98	8.12	94.18	48.89	4.6	43.7
1985	12	15	.0	2446414.5	23 17.004	+ 3 42.43	23 18.836	+ 3 54.24	.821	1.272	5.94	8.12	89.13	50.67	4.9	42.5
1985	12	17	.0	2446416.5	23 6.880	+ 2 41.07	23 8.713	+ 2 52.77	.859	1.242	5.90	8.11	84.39	52.08	5.3	41.2
1985	12	19	.0	2446418.5	22 57.781	+ 1 45.65	22 59.616	+ 1 57.23	.898	1.211	5.85	8.10	79.92	53.15	5.7	39.9
1985	12	21	.0	2446420.5	22 49.579	+ 0 55.57	22 51.417	+ 1 7.04	.938	1.180	5.80	8.08	75.69	53.91	6.2	38.4
1985	12	23	.0	2446422.5	22 42.157	+ 0 10.26	22 43.999	+ 0 21.60	.978	1.149	5.74	8.05	71.68	54.38	6.6	36.9

Table B-2. Comet Halley Ephemeris for 1984-1986 (contd)

YR	MN	DY	HR	J.D.	R.A. 1950.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1985	12	25	.0	2446424.5	22 35.412	- 0 30.87	22 37.257	- 0 19.64	1.019	1.118	5.67	8.02	67.84	54.58	7.1	35.3
1985	12	27	.0	2446426.5	22 29.250	- 1 8.34	22 31.099	- 0 57.23	1.059	1.087	5.60	7.99	64.17	54.53	7.6	33.7
1985	12	29	.0	2446428.5	22 23.589	- 1 42.65	22 25.442	- 1 31.66	1.099	1.056	5.52	7.94	60.63	54.25	8.1	31.9
1985	12	31	.0	2446430.5	22 18.358	- 2 14.24	22 20.215	- 2 3.36	1.139	1.025	5.42	7.89	57.22	53.74	8.6	30.0
1986	1	2	.0	2446432.5	22 13.493	- 2 43.52	22 15.354	- 2 32.75	1.178	.995	5.32	7.83	53.90	53.02	9.2	27.9
1986	1	4	.0	2446434.5	22 8.938	- 3 10.83	22 10.803	- 3 .17	1.216	.964	5.22	7.77	50.67	52.08	9.7	25.8
1986	1	6	.0	2446436.5	22 4.644	- 3 36.51	22 6.513	- 3 25.95	1.253	.934	5.10	7.69	47.52	50.93	10.3	23.5
1986	1	8	.0	2446438.5	22 .567	- 4 .85	22 2.439	- 3 50.39	1.289	.904	4.98	7.61	44.42	49.58	11.0	21.0
1986	1	10	.0	2446440.5	21 56.666	- 4 24.12	21 58.542	- 4 13.77	1.323	.875	4.85	7.53	41.38	48.01	11.6	18.3
1986	1	12	.0	2446442.5	21 52.905	- 4 46.58	21 54.785	- 4 36.32	1.356	.846	4.71	7.43	38.39	46.23	12.2	15.5
1986	1	14	.0	2446444.5	21 49.252	- 5 8.45	21 51.136	- 4 58.29	1.387	.817	4.56	7.33	35.43	44.24	12.9	12.4
1986	1	16	.0	2446446.5	21 45.677	- 5 29.96	21 47.565	- 5 19.90	1.416	.790	4.41	7.23	32.50	42.01	13.6	9.1
1986	1	18	.0	2446448.5	21 42.154	- 5 51.31	21 44.046	- 5 41.36	1.444	.763	4.26	7.12	29.60	39.56	14.3	5.6
1986	1	20	.0	2446450.5	21 38.660	- 6 12.70	21 40.557	- 6 2.85	1.469	.737	4.10	7.01	26.72	36.88	14.9	1.7
1986	1	22	.0	2446452.5	21 35.176	- 6 34.30	21 37.077	- 6 24.55	1.491	.713	3.94	6.90	23.87	33.96	15.6	357.6
1986	1	24	.0	2446454.5	21 31.685	- 6 56.29	21 33.591	- 6 46.65	1.511	.690	3.78	6.78	21.04	30.81	16.2	353.2
1986	1	26	.0	2446456.5	21 28.174	- 7 18.81	21 30.084	- 7 9.28	1.528	.669	3.63	6.67	18.25	27.46	16.7	348.4
1986	1	28	.0	2446458.5	21 24.633	- 7 42.00	21 26.548	- 7 32.59	1.542	.649	3.48	6.56	15.51	23.93	17.2	343.3
1986	1	30	.0	2446460.5	21 21.057	- 8 5.99	21 22.978	- 7 56.69	1.553	.632	3.34	6.46	12.87	20.31	17.5	337.9
1986	2	1	.0	2446462.5	21 17.445	- 8 30.88	21 19.371	- 8 21.70	1.560	.617	3.22	6.37	10.40	16.74	17.7	332.2
1986	2	3	.0	2446464.5	21 13.800	- 8 56.73	21 15.731	- 8 47.67	1.564	.605	3.11	6.29	8.27	13.55	17.8	326.3
1986	2	5	.0	2446466.5	21 10.128	- 9 23.60	21 12.065	- 9 14.68	1.563	.596	3.03	6.22	6.84	11.36	17.6	320.1
1986	2	7	.0	2446468.5	21 6.439	- 9 51.54	21 8.383	- 9 42.74	1.559	.590	2.96	6.17	6.57	11.03	17.2	313.8
1986	2	9	.0	2446470.5	21 2.747	-10 20.54	21 4.698	-10 11.87	1.551	.587	2.92	6.14	7.61	12.85	16.7	307.4
1986	2	11	.0	2446472.5	20 59.064	-10 50.60	21 1.022	-10 42.07	1.538	.588	2.96	6.13	9.53	16.13	15.9	301.1
1986	2	13	.0	2446474.5	20 55.404	-11 21.72	20 57.369	-11 13.33	1.522	.592	3.00	6.13	11.91	20.14	15.0	294.8
1986	2	15	.0	2446476.5	20 51.778	-11 53.89	20 53.751	-11 45.63	1.501	.599	3.09	6.15	14.52	24.43	13.9	288.7
1986	2	17	.0	2446478.5	20 48.195	-12 27.11	20 50.176	-12 18.99	1.477	.609	3.25	6.19	17.26	28.78	12.7	282.9
1986	2	19	.0	2446480.5	20 44.657	-13 1.42	20 46.647	-12 53.44	1.450	.622	3.46	6.24	20.06	33.04	11.4	277.3
1986	2	21	.0	2446482.5	20 41.165	-13 36.87	20 43.163	-13 29.02	1.419	.638	3.72	6.31	22.91	37.14	10.1	272.0
1986	2	23	.0	2446484.5	20 37.709	-14 13.55	20 39.717	-14 5.84	1.386	.656	4.00	6.37	25.77	41.02	8.8	267.1
1986	2	25	.0	2446486.5	20 34.278	-14 51.61	20 36.295	-14 44.04	1.349	.676	4.28	6.45	28.66	44.65	7.5	262.4
1986	2	27	.0	2446488.5	20 30.851	-15 31.24	20 32.879	-15 23.81	1.310	.698	4.53	6.52	31.57	48.01	6.2	258.1
1986	3	1	.0	2446490.5	20 27.405	-16 12.67	20 29.444	-16 5.38	1.269	.721	4.74	6.60	34.50	51.10	5.0	254.0
1986	3	3	.0	2446492.5	20 23.907	-16 56.20	20 25.957	-16 49.06	1.226	.746	4.90	6.67	37.45	53.91	3.8	250.3
1986	3	5	.0	2446494.5	20 20.318	-17 42.20	20 22.380	-17 35.22	1.182	.772	5.00	6.74	40.44	56.44	2.7	246.7
1986	3	7	.0	2446496.5	20 16.590	-18 31.11	20 18.665	-18 24.28	1.135	.799	5.04	6.80	43.47	58.69	1.7	243.5
1986	3	9	.0	2446498.5	20 12.666	-19 23.45	20 14.756	-19 16.80	1.088	.827	5.04	6.86	46.56	60.66	.7	240.4
1986	3	11	.0	2446500.5	20 8.477	-20 19.85	20 10.582	-20 13.38	1.039	.855	5.01	6.91	49.72	62.35	-.2	237.6
1986	3	13	.0	2446502.5	20 3.937	-21 21.04	20 6.060	-21 14.77	.990	.885	4.95	6.94	52.97	63.76	-1.0	234.9
1986	3	15	.0	2446504.5	19 58.943	-22 27.88	20 1.086	-22 21.84	.939	.914	4.87	6.97	56.34	64.87	-1.8	232.4
1986	3	17	.0	2446506.5	19 53.364	-23 41.41	19 55.529	-23 35.61	.889	.944	4.78	6.99	59.84	65.67	-2.6	230.0
1986	3	19	.0	2446508.5	19 47.034	-25 2.79	19 49.224	-24 57.29	.838	.974	4.69	7.00	63.53	66.14	-3.3	227.8
1986	3	21	.0	2446510.5	19 39.739	-26 33.38	19 41.958	-26 28.23	.787	1.005	4.60	7.00	67.43	66.24	-3.9	225.8
1986	3	23	.0	2446512.5	19 31.195	-28 14.70	19 33.449	-28 9.96	.737	1.036	4.50	6.99	71.60	65.94	-4.5	223.8
1986	3	25	.0	2446514.5	19 21.029	-30 8.32	19 23.323	-30 4.07	.687	1.066	4.41	6.96	76.09	65.19	-5.1	222.0
1986	3	27	.0	2446516.5	19 8.733	-32 15.67	19 11.075	-32 12.04	.639	1.097	4.32	6.93	80.98	63.90	-5.6	220.3
1986	3	29	.0	2446518.5	18 53.619	-34 37.61	18 56.016	-34 34.74	.593	1.128	4.23	6.89	86.35	62.02	-6.1	218.6
1986	3	31	.0	2446520.5	18 34.756	-37 13.49	18 37.218	-37 11.60	.550	1.159	4.15	6.84	92.29	59.43	-6.6	217.0
1986	4	2	.0	2446522.5	18 10.934	-39 59.58	18 13.467	-39 58.93	.510	1.190	4.07	6.79	98.88	56.07	-7.0	215.6
1986	4	4	.0	2446524.5	17 40.711	-42 46.43	17 43.313	-42 47.38	.475	1.221	4.00	6.75	106.18	51.87	-7.4	214.1
1986	4	6	.0	2446526.5	17 2.769	-45 15.92	17 5.418	-45 18.85	.447	1.252	3.96	6.73	114.13	46.84	-7.8	212.8
1986	4	8	.0	2446528.5	16 16.833	-47 .35	16 19.474	-47 5.56	.427	1.283	3.95	6.74	122.56	41.14	-8.2	211.5
1986	4	10	.0	2446530.5	15 25.019	-47 29.07	15 27.569	-47 36.60	.417	1.314	3.99	6.78	131.02	35.13	-8.5	210.3
1986	4	12	.0	2446532.5	14 32.177	-46 24.34	14 34.563	-46 33.84	.417	1.344	4.07	6.88	138.78	29.43	-8.8	209.1
1986	4	14	.0	2446534.5	13 43.747	-43 54.61	13 45.950	-44 5.48	.427	1.375	4.21	7.04	144.92	24.79	-9.1	208.0
1986	4	16	.0	2446536.5	13 2.960	-40 29.48	13 5.010	-40 41.13	.448	1.405	4.39	7.23	148.53	21.89	-9.4	206.9

Table B-2. Comet Halley Ephemeris for 1984-1986 (contd)

YR	MN	DY	HR	J.D.	R.A. 1950.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1986	4	18	.0	2446538.5	12 30.294	-36 42.32	12 32.235	-36 54.33	.478	1.436	4.60	7.47	149.30	20.92	-9.7	205.9
1986	4	20	.0	2446540.5	12 4.679	-32 57.91	12 6.551	-33 10.03	.515	1.466	4.83	7.72	147.75	21.45	-10.0	204.9
1986	4	22	.0	2446542.5	11 44.656	-29 30.04	11 46.487	-29 42.15	.558	1.496	5.07	7.98	144.82	22.77	-10.2	204.0
1986	4	24	.0	2446544.5	11 28.912	-26 24.25	11 30.719	-26 36.28	.606	1.526	5.31	8.25	141.25	24.36	-10.4	203.1
1986	4	26	.0	2446546.5	11 16.414	-23 41.31	11 18.209	-23 53.23	.658	1.556	5.53	8.51	137.51	25.90	-10.7	202.2
1986	4	28	.0	2446548.5	11 6.394	-21 19.66	11 8.182	-21 31.47	.713	1.586	5.76	8.77	133.82	27.26	-10.9	201.3
1986	4	30	.0	2446550.5	10 58.285	-19 16.89	11 .071	-19 28.60	.770	1.615	5.96	9.02	130.27	28.41	-11.1	200.5
1986	5	2	.0	2446552.5	10 51.671	-17 30.48	10 53.457	-17 42.09	.829	1.645	6.16	9.25	126.89	29.34	-11.3	199.7
1986	5	4	.0	2446554.5	10 46.242	-15 58.04	10 48.031	-16 9.57	.890	1.674	6.35	9.49	123.69	30.07	-11.4	199.0
1986	5	6	.0	2446556.5	10 41.768	-14 37.51	10 43.560	-14 48.97	.952	1.704	6.52	9.71	120.66	30.62	-11.6	198.2
1986	5	8	.0	2446558.5	10 38.072	-13 27.13	10 39.866	-13 38.52	1.015	1.733	6.69	9.92	117.78	31.02	-11.8	197.5
1986	5	10	.0	2446560.5	10 35.015	-12 25.41	10 36.813	-12 36.74	1.078	1.762	6.84	10.12	115.04	31.28	-11.9	196.8
1986	5	12	.0	2446562.5	10 32.493	-11 31.10	10 34.294	-11 42.39	1.143	1.791	6.99	10.32	112.42	31.43	-12.1	196.2
1986	5	14	.0	2446564.5	10 30.419	-10 43.19	10 32.223	-10 54.44	1.207	1.819	7.13	10.51	109.91	31.48	-12.2	195.5
1986	5	16	.0	2446566.5	10 28.726	-10 .81	10 30.533	-10 12.03	1.273	1.848	7.26	10.69	107.49	31.45	-12.4	194.9
1986	5	18	.0	2446568.5	10 27.358	- 9 23.23	10 29.169	- 9 34.42	1.338	1.877	7.39	10.87	105.16	31.35	-12.5	194.3
1986	5	20	.0	2446570.5	10 26.271	- 8 49.85	10 28.084	- 9 1.02	1.404	1.905	7.51	11.03	102.90	31.18	-12.6	193.7
1986	5	22	.0	2446572.5	10 25.426	- 8 20.16	10 27.242	- 8 31.31	1.469	1.933	7.62	11.20	100.71	30.97	-12.8	193.1
1986	5	24	.0	2446574.5	10 24.793	- 7 53.72	10 26.612	- 8 4.86	1.535	1.961	7.73	11.36	98.58	30.70	-12.9	192.5
1986	5	26	.0	2446576.5	10 24.346	- 7 30.15	10 26.167	- 7 41.28	1.601	1.989	7.84	11.51	96.50	30.40	-13.0	192.0
1986	5	28	.0	2446578.5	10 24.063	- 7 9.15	10 25.887	- 7 20.28	1.667	2.017	7.95	11.66	94.47	30.06	-13.1	191.5
1986	5	30	.0	2446580.5	10 23.927	- 6 50.44	10 25.752	- 7 1.57	1.732	2.045	8.05	11.80	92.48	29.69	-13.2	191.0
1986	6	1	.0	2446582.5	10 23.922	- 6 33.81	10 25.749	- 6 44.94	1.798	2.072	8.15	11.94	90.53	29.29	-13.3	190.5
1986	6	3	.0	2446584.5	10 24.033	- 6 19.04	10 25.862	- 6 30.17	1.863	2.100	8.25	12.07	88.61	28.88	-13.4	190.0
1986	6	5	.0	2446586.5	10 24.250	- 6 5.96	10 26.081	- 6 17.10	1.928	2.127	8.34	12.20	86.73	28.44	-13.5	189.5
1986	6	7	.0	2446588.5	10 24.563	- 5 54.43	10 26.395	- 6 5.58	1.993	2.154	8.44	12.33	84.87	27.98	-13.6	189.0
1986	6	9	.0	2446590.5	10 24.961	- 5 44.31	10 26.795	- 5 55.47	2.058	2.181	8.54	12.45	83.04	27.51	-13.7	188.6
1986	6	11	.0	2446592.5	10 25.437	- 5 35.48	10 27.272	- 5 46.65	2.122	2.208	8.63	12.57	81.24	27.03	-13.8	188.1
1986	6	13	.0	2446594.5	10 25.984	- 5 27.84	10 27.820	- 5 39.02	2.186	2.235	8.73	12.69	79.46	26.53	-13.9	187.7
1986	6	15	.0	2446596.5	10 26.595	- 5 21.28	10 28.432	- 5 32.48	2.249	2.262	8.82	12.81	77.70	26.02	-14.0	187.3
1986	6	17	.0	2446598.5	10 27.264	- 5 15.73	10 29.102	- 5 26.94	2.312	2.289	8.92	12.92	75.96	25.51	-14.0	186.9
1986	6	19	.0	2446600.5	10 27.985	- 5 11.10	10 29.824	- 5 22.33	2.375	2.315	9.02	13.02	74.24	24.98	-14.1	186.4
1986	6	21	.0	2446602.5	10 28.755	- 5 7.34	10 30.594	- 5 18.59	2.437	2.342	9.11	13.13	72.53	24.45	-14.2	186.1
1986	6	23	.0	2446604.5	10 29.568	- 5 4.37	10 31.409	- 5 15.63	2.498	2.368	9.21	13.23	70.84	23.92	-14.3	185.7
1986	6	25	.0	2446606.5	10 30.422	- 5 2.14	10 32.263	- 5 13.42	2.559	2.394	9.31	13.33	69.17	23.38	-14.3	185.3
1986	6	27	.0	2446608.5	10 31.313	- 5 .60	10 33.155	- 5 11.90	2.620	2.420	9.41	13.43	67.51	22.83	-14.4	184.9
1986	6	29	.0	2446610.5	10 32.238	- 4 59.71	10 34.081	- 5 11.03	2.679	2.446	9.51	13.53	65.86	22.28	-14.5	184.6
1986	7	1	.0	2446612.5	10 33.195	- 4 59.43	10 35.038	- 5 10.77	2.739	2.472	9.61	13.62	64.22	21.73	-14.5	184.2
1986	7	3	.0	2446614.5	10 34.182	- 4 59.73	10 36.025	- 5 11.09	2.797	2.498	9.71	13.71	62.59	21.18	-14.6	183.8
1986	7	5	.0	2446616.5	10 35.195	- 5 .56	10 37.039	- 5 11.95	2.855	2.524	9.81	13.80	60.97	20.63	-14.6	183.5
1986	7	7	.0	2446618.5	10 36.232	- 5 1.91	10 38.077	- 5 13.32	2.913	2.549	9.91	13.89	59.36	20.07	-14.7	183.2
1986	7	9	.0	2446620.5	10 37.293	- 5 3.74	10 39.138	- 5 15.17	2.969	2.575	10.01	13.97	57.76	19.51	-14.8	182.8
1986	7	11	.0	2446622.5	10 38.373	- 5 6.03	10 40.219	- 5 17.48	3.025	2.600	10.12	14.05	56.17	18.95	-14.8	182.5
1986	7	13	.0	2446624.5	10 39.472	- 5 8.74	10 41.318	- 5 20.22	3.080	2.626	10.22	14.14	54.59	18.40	-14.9	182.2
1986	7	15	.0	2446626.5	10 40.587	- 5 11.86	10 42.434	- 5 23.36	3.135	2.651	10.32	14.21	53.02	17.84	-14.9	181.9
1986	7	17	.0	2446628.5	10 41.718	- 5 15.37	10 43.564	- 5 26.88	3.188	2.676	10.42	14.29	51.45	17.28	-15.0	181.6
1986	7	19	.0	2446630.5	10 42.861	- 5 19.23	10 44.708	- 5 30.77	3.241	2.701	10.53	14.37	49.90	16.73	-15.0	181.3
1986	7	21	.0	2446632.5	10 44.016	- 5 23.43	10 45.864	- 5 34.99	3.293	2.726	10.63	14.44	48.34	16.17	-15.1	181.0
1986	7	23	.0	2446634.5	10 45.182	- 5 27.97	10 47.030	- 5 39.55	3.344	2.751	10.73	14.52	46.80	15.62	-15.1	180.7
1986	7	25	.0	2446636.5	10 46.358	- 5 32.80	10 48.206	- 5 44.41	3.395	2.775	10.84	14.59	45.26	15.07	-15.2	180.4
1986	7	27	.0	2446638.5	10 47.542	- 5 37.94	10 49.390	- 5 49.56	3.444	2.800	10.94	14.66	43.73	14.52	-15.2	180.1
1986	7	29	.0	2446640.5	10 48.734	- 5 43.36	10 50.582	- 5 55.00	3.493	2.825	11.04	14.73	42.21	13.98	-15.2	179.9
1986	7	31	.0	2446642.5	10 49.932	- 5 49.05	10 51.781	- 6 .72	3.541	2.849	11.14	14.79	40.69	13.43	-15.3	179.6
1986	8	2	.0	2446644.5	10 51.136	- 5 55.00	10 52.985	- 6 6.69	3.588	2.873	11.24	14.86	39.19	12.90	-15.3	179.3
1986	8	4	.0	2446646.5	10 52.345	- 6 1.20	10 54.194	- 6 12.90	3.633	2.898	11.35	14.92	37.68	12.36	-15.4	179.1
1986	8	6	.0	2446648.5	10 53.557	- 6 7.63	10 55.407	- 6 19.36	3.678	2.922	11.44	14.98	36.19	11.83	-15.4	178.8
1986	8	8	.0	2446650.5	10 54.771	- 6 14.29	10 56.621	- 6 26.04	3.722	2.946	11.54	15.05	34.71	11.30	-15.4	178.6

Table B-2. Comet Halley Ephemeris for 1984-1986 (contd)

YR	MN	DY	HR	J.D.	R.A. 1950.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1986	8	10	.0	2446652.5	10 55.987	- 6 21.17	10 57.838	- 6 32.93	3.766	2.970	11.64	15.11	33.23	10.78	-15.5	178.3
1986	8	12	.0	2446654.5	10 57.204	- 6 28.24	10 59.054	- 6 40.03	3.808	2.994	11.74	15.17	31.77	10.27	-15.5	178.1
1986	8	14	.0	2446656.5	10 58.420	- 6 35.52	11 .270	- 6 47.32	3.849	3.018	11.83	15.22	30.32	9.76	-15.6	177.8
1986	8	16	.0	2446658.5	10 59.634	- 6 42.97	11 1.485	- 6 54.79	3.889	3.042	11.93	15.28	28.88	9.25	-15.6	177.6
1986	8	18	.0	2446660.5	11 .846	- 6 50.60	11 2.697	- 7 2.44	3.928	3.065	12.02	15.34	27.46	8.76	-15.6	177.4
1986	8	20	.0	2446662.5	11 2.055	- 6 58.39	11 3.906	- 7 10.25	3.966	3.089	12.11	15.39	26.05	8.27	-15.7	177.1
1986	8	22	.0	2446664.5	11 3.260	- 7 6.35	11 5.112	- 7 18.23	4.003	3.113	12.20	15.44	24.67	7.79	-15.7	176.9
1986	8	24	.0	2446666.5	11 4.461	- 7 14.45	11 6.313	- 7 26.35	4.039	3.136	12.29	15.50	23.31	7.33	-15.7	176.7
1986	8	26	.0	2446668.5	11 5.657	- 7 22.71	11 7.509	- 7 34.62	4.074	3.160	12.37	15.55	21.98	6.88	-15.7	176.5
1986	8	28	.0	2446670.5	11 6.847	- 7 31.10	11 8.700	- 7 43.03	4.108	3.183	12.46	15.60	20.68	6.44	-15.8	176.2
1986	8	30	.0	2446672.5	11 8.031	- 7 39.63	11 9.884	- 7 51.57	4.141	3.206	12.54	15.65	19.43	6.01	-15.8	176.0
1986	9	1	.0	2446674.5	11 9.207	- 7 48.29	11 11.061	- 8 .24	4.172	3.229	12.62	15.69	18.23	5.61	-15.8	175.8
1986	9	3	.0	2446676.5	11 10.376	- 7 57.06	11 12.230	- 8 9.04	4.203	3.252	12.70	15.74	17.09	5.23	-15.9	175.6
1986	9	5	.0	2446678.5	11 11.535	- 8 5.96	11 13.390	- 8 17.95	4.233	3.275	12.78	15.79	16.03	4.88	-15.9	175.4
1986	9	7	.0	2446680.5	11 12.685	- 8 14.96	11 14.540	- 8 26.96	4.261	3.298	12.85	15.83	15.07	4.56	-15.9	175.2
1986	9	9	.0	2446682.5	11 13.824	- 8 24.06	11 15.679	- 8 36.08	4.289	3.321	12.92	15.87	14.22	4.27	-15.9	175.0
1986	9	11	.0	2446684.5	11 14.951	- 8 33.26	11 16.807	- 8 45.29	4.315	3.344	12.99	15.92	13.51	4.03	-16.0	174.8
1986	9	13	.0	2446686.5	11 16.066	- 8 42.54	11 17.922	- 8 54.58	4.340	3.367	13.06	15.96	12.96	3.84	-16.0	174.6
1986	9	15	.0	2446688.5	11 17.167	- 8 51.91	11 19.024	- 9 3.96	4.364	3.390	13.13	16.00	12.60	3.71	-16.0	174.4
1986	9	17	.0	2446690.5	11 18.255	- 9 1.34	11 20.112	- 9 13.41	4.387	3.412	13.19	16.04	12.44	3.64	-16.1	174.2
1986	9	19	.0	2446692.5	11 19.328	- 9 10.85	11 21.185	- 9 22.93	4.409	3.435	13.25	16.08	12.49	3.63	-16.1	174.1
1986	9	21	.0	2446694.5	11 20.385	- 9 20.43	11 22.243	- 9 32.52	4.429	3.457	13.31	16.12	12.76	3.68	-16.1	173.9
1986	9	23	.0	2446696.5	11 21.426	- 9 30.07	11 23.285	- 9 42.17	4.449	3.480	13.37	16.16	13.22	3.78	-16.1	173.7
1986	9	25	.0	2446698.5	11 22.451	- 9 39.76	11 24.310	- 9 51.87	4.468	3.502	13.42	16.19	13.87	3.94	-16.1	173.5
1986	9	27	.0	2446700.5	11 23.458	- 9 49.50	11 25.318	-10 1.63	4.485	3.524	13.48	16.23	14.68	4.13	-16.2	173.3
1986	9	29	.0	2446702.5	11 24.446	- 9 59.30	11 26.306	-10 11.43	4.501	3.547	13.53	16.26	15.63	4.36	-16.2	173.2
1986	10	1	.0	2446704.5	11 25.415	-10 9.13	11 27.276	-10 21.27	4.516	3.569	13.57	16.30	16.69	4.62	-16.2	173.0
1986	10	3	.0	2446706.5	11 26.363	-10 19.00	11 28.224	-10 31.15	4.530	3.591	13.62	16.33	17.86	4.90	-16.2	172.8
1986	10	5	.0	2446708.5	11 27.289	-10 28.90	11 29.151	-10 41.06	4.543	3.613	13.66	16.37	19.10	5.20	-16.3	172.6
1986	10	7	.0	2446710.5	11 28.193	-10 38.82	11 30.055	-10 50.98	4.555	3.635	13.70	16.40	20.41	5.50	-16.3	172.5
1986	10	9	.0	2446712.5	11 29.073	-10 48.75	11 30.936	-11 .93	4.566	3.657	13.74	16.43	21.78	5.82	-16.3	172.3
1986	10	11	.0	2446714.5	11 29.928	-10 58.69	11 31.791	-11 10.88	4.575	3.679	13.78	16.46	23.20	6.14	-16.3	172.1
1986	10	13	.0	2446716.5	11 30.757	-11 8.64	11 32.621	-11 20.83	4.584	3.701	13.81	16.49	24.66	6.46	-16.3	172.0
1986	10	15	.0	2446718.5	11 31.560	-11 18.58	11 33.424	-11 30.78	4.591	3.722	13.84	16.52	26.16	6.78	-16.3	171.8
1986	10	17	.0	2446720.5	11 32.335	-11 28.51	11 34.200	-11 40.72	4.598	3.744	13.87	16.55	27.69	7.11	-16.4	171.7
1986	10	19	.0	2446722.5	11 33.081	-11 38.43	11 34.947	-11 50.64	4.603	3.766	13.90	16.57	29.25	7.43	-16.4	171.5
1986	10	21	.0	2446724.5	11 33.798	-11 48.33	11 35.664	-12 .55	4.607	3.787	13.92	16.60	30.84	7.74	-16.4	171.4
1986	10	23	.0	2446726.5	11 34.484	-11 58.21	11 36.351	-12 10.43	4.611	3.809	13.95	16.63	32.45	8.06	-16.4	171.2
1986	10	25	.0	2446728.5	11 35.139	-12 8.05	11 37.006	-12 20.28	4.613	3.830	13.97	16.65	34.09	8.37	-16.4	171.1
1986	10	27	.0	2446730.5	11 35.760	-12 17.86	11 37.628	-12 30.10	4.614	3.851	13.99	16.68	35.74	8.67	-16.5	170.9
1986	10	29	.0	2446732.5	11 36.348	-12 27.62	11 38.216	-12 39.86	4.615	3.873	14.00	16.70	37.42	8.97	-16.5	170.8
1986	10	31	.0	2446734.5	11 36.899	-12 37.34	11 38.768	-12 49.58	4.614	3.894	14.02	16.72	39.11	9.26	-16.5	170.6
1986	11	2	.0	2446736.5	11 37.415	-12 46.99	11 39.284	-12 59.24	4.612	3.915	14.03	16.75	40.82	9.54	-16.5	170.5
1986	11	4	.0	2446738.5	11 37.892	-12 56.57	11 39.761	-13 8.82	4.610	3.937	14.05	16.77	42.55	9.81	-16.5	170.3
1986	11	6	.0	2446740.5	11 38.329	-13 6.08	11 40.199	-13 18.33	4.606	3.958	14.06	16.79	44.30	10.07	-16.5	170.2
1986	11	8	.0	2446742.5	11 38.725	-13 15.49	11 40.596	-13 27.75	4.602	3.979	14.07	16.81	46.06	10.33	-16.6	170.1
1986	11	10	.0	2446744.5	11 39.080	-13 24.82	11 40.951	-13 37.08	4.597	4.000	14.07	16.83	47.84	10.58	-16.6	169.9
1986	11	12	.0	2446746.5	11 39.391	-13 34.03	11 41.262	-13 46.30	4.591	4.021	14.08	16.85	49.63	10.81	-16.6	169.8
1986	11	14	.0	2446748.5	11 39.658	-13 43.14	11 41.530	-13 55.41	4.584	4.042	14.08	16.87	51.44	11.04	-16.6	169.6
1986	11	16	.0	2446750.5	11 39.879	-13 52.13	11 41.751	-14 4.40	4.576	4.062	14.09	16.89	53.26	11.25	-16.6	169.5
1986	11	18	.0	2446752.5	11 40.053	-14 .98	11 41.925	-14 13.26	4.568	4.083	14.09	16.91	55.10	11.45	-16.6	169.4
1986	11	20	.0	2446754.5	11 40.179	-14 9.70	11 42.052	-14 21.98	4.558	4.104	14.09	16.93	56.95	11.64	-16.6	169.2
1986	11	22	.0	2446756.5	11 40.256	-14 18.28	11 42.128	-14 30.56	4.549	4.125	14.09	16.94	58.82	11.82	-16.7	169.1
1986	11	24	.0	2446758.5	11 40.282	-14 26.69	11 42.154	-14 38.97	4.538	4.145	14.09	16.96	60.70	11.99	-16.7	169.0
1986	11	26	.0	2446760.5	11 40.255	-14 34.94	11 42.127	-14 47.22	4.527	4.166	14.09	16.98	62.60	12.14	-16.7	168.9
1986	11	28	.0	2446762.5	11 40.174	-14 43.00	11 42.047	-14 55.28	4.515	4.187	14.09	16.99	64.52	12.28	-16.7	168.7
1986	11	30	.0	2446764.5	11 40.038	-14 50.87	11 41.911	-15 3.16	4.503	4.207	14.09	17.01	66.45	12.41	-16.7	168.6